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Environmental Considerations for Vegetation in Flood Control Channels

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Environmental Considerations for Vegetation in Flood Control Channels

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Preface

This report was prepared at the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, by personnel of the Environmental Engineering Division (EED), Environmental Laboratory (EL), and the Estuaries and Hydroscience Division (CE) and the Rivers and Structures Division (CR), Coastal and Hydraulics Laboratory (CHL), as part of the Flood Damage Reduction Research Program (FDRRP). The FDRRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to ERDC under the purview of CHL. The HQUSACE Technical Monitor was Mr. Tom Munsey (retired) and Mr. Richard DiBuono (retired). Dr. Ronald Copeland, CHL, was the FDRRP Program Manager.

The study was performed under the direct supervision of Mr. Norman Francingues, Chief, EED; Dr. Edwin A. Theriot, Director, EL; Mr. William McAnally, Jr., Chief, CE; Dr. Phil Combs, Chief, CR; and Mr. Thomas W. Richardson, Acting Director, CHL. The report was prepared by Dr. J. Craig Fischenich, EL, and Dr. Copeland.

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1 Introduction

Background

The ability to predict or account for impacts associated with vegetation on streams and flood control projects is hampered by a lack of understanding of the physical processes that occur when water flows through and over vegetation. Vegetation can cause conveyance loss, induce sediment stability problems, increase flooding, and disrupt normal channel-floodplain interactions. The tools typically used for evaluating open channel flow do not typically allow for consideration of the varied effects of vegetation. Therefore, hydraulic engineers have long been reluctant to incorporate many types of vegetation into designs because of the hydraulic and sediment uncertainties.

But healthy riparian vegetation also stabilizes streambanks, provides shade that prevents excessive water temperature fluctuations, performs a vital role in nutrient cycling and water quality, improves aesthetic and recreational benefits of a site, and is immensely productive as wildlife habitat. For these reasons, the incorporation of vegetation in stream restoration and flood control projects is often desirable.

Purpose

This report describes the environmental benefits of riparian vegetation and presents considerations for the incorporation of riparian vegetation into the design and maintenance of flood control projects. The report is directed toward hydraulic engineers involved in flood control channel design as well as stream restoration and habitat improvement projects.

2 The Riparian Environment

Background

Riparian ecosystems occur along streams and rivers. The riparian corridor (Figure 1) encompasses the stream channel and that portion of the terrestrial landscape from the water's edge landward, where vegetation may be influenced by river-associated water tables or flooding and by the ability of soils to hold water (Naiman, Decamps, and Pollock 1993). Riparian corridors do not include terraces or other elevations in the geomorphic floodplain that are not periodically connected with surface water of the present river. The term "riparian vegetation" refers to the vegetation found growing within the riparian corridor.

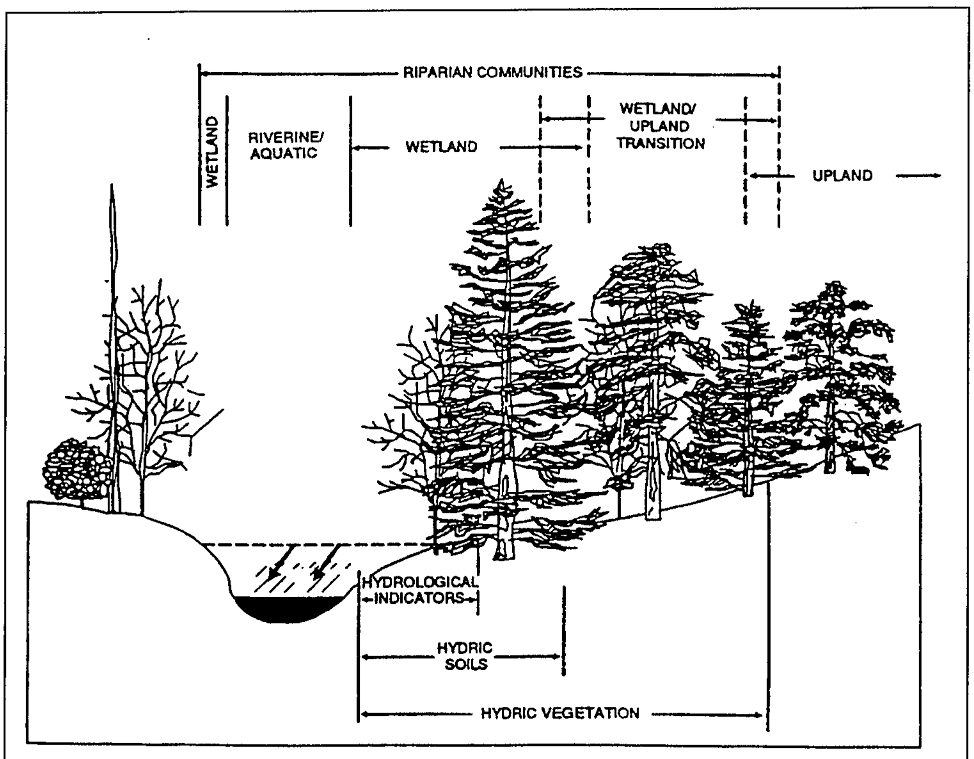

Figure 1. Relationship of aquatic, wetland, and upland areas within riparian corridors

Ecological investigations of riparian corridors have shown them to be key landscape features with unusually high levels of biodiversity (Naiman, Decamps, and Pollock 1993). Riparian habitats form a mosaic of communities differing in species and structure which allows a wide variety of species to co-exist (Naiman, Decamps, and Pollock 1993). Furthermore, the mosaic of habitats within many riparian corridors is in constant flux. Newly created habitats shift over time and in space as point bars are created by the river dynamics, mature into different types of communities, and are eventually eroded away as the river continues to change position. Characteristics such as the flood regime and energy of the river system determine how rapidly these processes occur and the degree of maturation reached by the vegetation. This dynamic equilibrium of habitats results in a diversity of vegetation composition, age, density, and structure.

The presence and dynamic nature of riparian vegetation pose problems for hydraulic engineers estimating resistance of the vegetation to flow in flood control channels. Resistance coefficients of vegetation are highly variable depending on plant structure and density and are not well understood. Traditional management approaches for floodways attempt to minimize the amount of riparian vegetation, particularly woody vegetation. Whether considering natural or constructed systems, however, the presence of riparian vegetation enhances the environmental value of floodways. Furthermore, vegetation management to minimize flow resistance is expensive and is becoming more difficult to justify as the environmental value of riparian vegetation is becoming more clearly understood.

The value of riparian vegetation is derived from the environmental processes to which it contributes. For example, riparian vegetation helps stabilize banks which is valuable because otherwise expensive structures would have to be built to stabilize the bank. The environmental processes that take place in riparian ecosystems can be termed the functions of the ecosystem (Brinson 1993).

Not all functions are performed in all riparian ecosystems nor are all functions performed equally in all riparian ecosystems. Contributions of vegetation to riparian ecosystem functions depend to a large degree on the physical configuration of the river or steam system. For example, retention of nutrients flowing from surrounding uplands into a low gradient river with a wide, vegetated floodplain is likely to be greater than nutrient retention in a narrow, sparsely vegetated riparian buffer along a high gradient river. Both types of riparian systems exist naturally in the landscape, and both levels of nutrient retention are acceptable in their respective systems. There is greater value to society of the nutrient retention properties of the wide, vegetated floodplain than the narrow, sparsely vegetation riparian buffer if river water quality is a problem.

The objectives of this chapter are to introduce an ecological concept of the riparian corridor and the environmental factors that influence the composition, distribution, and structure of riparian vegetation. The following chapter describes the influences riparian vegetation has on the riparian environment.

Types of Riparian Vegetation

Few eastern plant species are found exclusively in riparian areas. Most riparian species will grow well in upland situations. However, they are at a competitive advantage under the conditions found in riparian areas. For example, bald cypress trees usually occur in southeastern swamps having long periods of annual flooding. These trees will also grow in surrounding upland communities and, in fact, are often used for landscaping. Cypress does not dominate upland plant communities because it cannot become established in the shade under existing vegetation or it is burned out by the periodic fires that are common in the Southeast. Upland plant species, on the other hand, often are not tolerant of the conditions found in riparian areas. Riparian plant species in the moister eastern portion of the country must be able to tolerate periods of inundation. Eastern riparian species such as bald cypress that do not grow well in the presence of more aggressive upland species are able to flourish along rivers and streams where upland species are excluded.

In contrast, many western riparian plant species are restricted to the relatively moist conditions along streams and rivers or other types of wetlands. Seedling establishment of many riparian species requires a moist ground surface for a sufficient period of time to allow the seed to germinate and establish a root system that can follow receding groundwater level. For example, Segelquist, Scott, and Auble (1993) showed that cottonwood establishment was restricted if groundwater levels receded faster than seedling roots could grow.

Other limiting conditions exist for plants in riparian areas. Species intolerant of abrasion or sediment deposition may be excluded from high-energy riparian areas. Riparian plant species that occur near active channels, such as willow (*Salix* spp) and cottonwood (*Populus* spp), commonly are very flexible and have the capacity to resprout after damage. Flexibility helps minimize damage during high flows. Because establishment by seed in riparian areas is difficult, it is a distinct advantage for a broken plant to be able to resprout and utilize the energy stored in the established root system. If plants are broken or stripped of leaves, they must be able to recover rapidly to survive subsequent high-flow events. Rapid recovery also ensures that the plant will outcompete new colonizing plants.

Excessive deposition of sediments is detrimental to plants primarily because oxygen diffusion to the roots is restricted. Roots require oxygen for respiration and usually cannot live long in the absence of oxygen. The depth of sediment required to block oxygen depends on the texture. Experimental deposits of 8 cm of sediments on a saltmarsh grass (*Spartina alterniflora*) reduced stem densities, with clays having a greater effect than equal depths of sand (Reimold, Hardisky, and Adams 1978). In addition, seedbanks are smothered by deposition, restricting the capability of plants to reestablish themselves following a catastrophic depositional event (Jurik, Wang, and van der Valk 1994). Furthermore, siltation on leaves harms plants by blocking light for photosynthesis. Therefore, while a certain amount of deposition in riparian areas is natural and desirable to replenish nutrients, excessive deposition limits plant distributions.

Species that are tolerant of deposition have several survival mechanisms. Some herbaceous species can grow up through the overlying material. Vines, such as blackberries (*Rubus* spp) and morning glories (*Ipomoea* spp), and grasses that spread with underground stems, such as reed canary grass and common reed, produce roots along the stem and continue to grow from the tips following deposition. The deeply buried portion of the plant may eventually die. Woody species are usually less adaptable. Some woody species, however, such as willow, are capable of producing adventitious roots on the aerated portion of the stem and of surviving deposits up to 1-m depth (U.S. Army Engineer Research and Development Center (ERDC) unpublished data).

While many plant species occur in riparian areas because they are tolerant of the conditions, life history characteristics of some riparian species restrict them to areas with flowing water and newly deposited sediments. Examples include several western willows and cottonwoods. Flowing water carries their seeds and deposits them on exposed areas, such as sand bars. The seeds have adequate moisture in these areas to enable them to establish a root system that is capable of following the receding water levels and soil moisture (Fowells 1965). These plants require full sunlight to survive and grow and are not capable of growth under existing vegetation. The constant creation of exposed sites by the river is necessary for regeneration of these trees (Everitt 1968, Fonda 1974, Noble 1979). These conditions are found only in or near active channels. Hence regeneration of these species is not found in other areas of riparian corridors.

Species distributions

Riparian corridors form links among many portions of the landscape and, as a consequence, have high levels of biodiversity. Biodiversity is best documented for plants, although nearly 70 percent of vertebrate species in a region will use riparian corridors during their life cycle (Raedeke 1989). Up to 20 percent of local floras have been estimated to occur in riparian corridors in Sweden (Nilsson 1992), the Amazon basin (Junk 1989), and France (Tabacchi, Planty-Tabacchi, and Dechamps 1990). The high diversity of riparian vascular plants is thought to be related to (a) the intensity and frequency of floods, (b) small-scale variations in topography and soils as a result of lateral migration of river channels, (c) variations in climate as streams flow from high to low altitudes or across biomes, and (d) disturbance regimes imposed on the riparian corridor by upland environments. The migration capacity of plants along riparian corridors is also an important factor in explaining the high biodiversity observed along river courses. Collectively, these forces create a mosaic of riparian habitats which allow a wide variety of species to co-exist (Naiman, Decamps, and Pollock 1993).

The range of geographic areas in which plant species naturally grow varies widely (Appendix A). A few species such as green ash and poison ivy have nationwide distributions. Most species are restricted to a region that may consist of one to several states. Many riparian species that are limited to one area, however, have closely related species in the same genus, called congeners, in other riparian areas. For example, eastern cottonwood occurs in eastern riparian zones, while its congener Fremont cottonwood is common in arid western riparian

zones. Willow, cattail (*Typha* spp), and sedges (*Carex* spp) are other examples of widely distributed riparian genera. Although congeners may have some similar habitat requirements, a species usually cannot be planted and successfully grown outside its normal geographic distribution.

Species planted outside of their normal distribution are considered to be exotic species in the new area. Planting exotic species can be detrimental to native vegetation, because the natural controls on the now exotic species are not transferred from the native range. With no controls, such as insects or fungi, to keep plants suppressed exotic species can become a nuisance by out-competing and eliminating native vegetation.

Riparian zones in different parts of the country have characteristic plant species assemblages. The assemblages result from controls on the vegetation from local climate, watershed physical and chemical characteristics, hydrologic regime, disturbances such as grazers or fire, and other natural and man-induced forces in the environment. The assemblages are typically dominated by a few species that determine the characteristic structure and functions of the riparian zone.

Aboveground structure

Dynamics of the stream interact closely with the vegetation structure. Early stages of riparian community development are largely determined by the hydrologic regime and energy in the riparian corridor. Flowing water exerts a physical control over species composition and structure that is reduced as plant structure becomes more robust with size (Adams and Viereck 1992). The aboveground structure of vegetation in riparian areas is characterized by the growth form, size, density, and aerial coverage of the plants.

Plants of all growth forms are found in riparian corridors (Table 1), but freshwater riparian areas are often dominated by trees, shrubs, and vines. Both eastern and western early successional riparian forests are often dominated by willows, cottonwoods, and alders (*Alnus* spp). Mature riparian forests are often dominated by other species. Bottomland hardwood forests of the Southeast, for example, are one of the most extensive and well studied types of wetlands in the country (Wharton, Kitchens,and Sipe 1982). These riparian forests are dominated by cypress (*Taxodium* spp), gum (*Nyssa* spp), oak (*Quercus* spp), ash (*Fraxinus* spp), and other tree species (Appendix A). Mature semiarid and arid western riparian forests may contain willow, cottonwood, ash, oaks, cedars (e.g., *Juniperus* spp), mesquite (*Prosopis* spp), and others (Appendix A).

The amount of herbaceous vegetation in the groundcover of a riparian forest depends on the amount of flooding and light an area receives. There is generally little herbaceous groundcover in forested areas that are flooded frequently or for long durations. Herbaceous vegetation is also sparse if trees form a closed canopy, and light is limited on the forest floor. Herbaceous vegetation can quickly become established, however, under gaps in the forest canopy.

Table 1
Characteristics of Plant Grown Forms in Riparian Areas

TREE
Tall, woody, long-lived plants that usually have a solitary trunk or main stem. Depending on species and latitude, leaves may be retained throughout the year (i.e., evergreen), have reduced numbers, or be completely lost each year (i.e., deciduous) from soon after first frost to last frost. Tree size is usually characterized as:
a) Canopy - Usually refers to the tallest trees in a forest that form the upper layer of vegetation; can be of any height ranging up to 50 m tall. b) Midstory - Trees that form a midlevel layer of leaves under a canopy; may include shade-tolerant or young canopy species; usually range in height from 5 to 15 m tall and have smaller stem diameters than canopy trees. c) Understory - Trees < 5 m tall; usually includes seedlings and saplings of midstory and canopy species.
Resistance - Well characterized for large trees and depends on vegetation type, condition, and density; resistance varies with relative height of water to level of canopy, presence of leaves, leaf stripping, deformation of small diameter stems and branches, and breakage; fallen trees and exposed root systems increase roughness of ground surfaces and stream beds.
SHRUB
A woody, long-lived plant that usually branches from the base with several main stems; usually small to medium size plants up to 5 m tall; may be the natural growth form of a species or formed by a resprouting tree with broken or fallen stems; may be evergreen or deciduous.
Resistance - Not well characterized; resistance varies with factors similar to trees.
VINE
A plant which climbs by tendrils or other means, or which trails or creeps along the ground; may be woody or herbaceous, long-lived or an annual species; may be evergreen or deciduous.
Resistance - Not well characterized; resistance varies with similar factors for trees as well as whether live annual species are present.
HERB
A vascular plant (i.e., not a moss or liverwort) that lacks a woody stem. Herbaceous species are characterized as either grasses and grasslike or forbs.
Grasses and grasslike - members of the Poaceae, Cyperaceae, or Juncaceae families; growth forms include sod, bunch, and trailing which differ in density and height of stems; heights usually range from 0.05 to 1 m tall but can be > 4 m tall; may be long-lived or annual species.
Resistance - Well characterized and varies with depth of water.
FORB
An herbaceous plant that is not a grass or grasslike species; wide range of size characteristics; usually < 1 m tall; may be long-lived or annual species.
Resistance - Not well characterized.

Herb dominated riparian areas usually occur in prairies where woody vegetation is limited (Figure 2) or where grazers, fire, or other factors prevent woody species from dominating. Historically, prairie cordgrass (*Spartina pectinata*) covered hundreds of square kilometers of bottomlands along the rivers and their tributaries throughout the tall-grass prairie region (Costello 1981). Sedges (e.g., *Carex* spp) and grasses (e.g., *Poa* spp, *Deschampsia* spp, and *Festuca* spp) commonly dominate western riparian areas where woody species are excluded (Youngblood, Padgett, and Winward 1985, Appendix A).

Woody species rarely dominate brackish or saltwater riparian areas because most of these species are intolerant of salinities above 5 ppt. Herbaceous species, therefore, usually dominate riparian areas with significant saltwater influences. *Spartina* spp and *Juncus* spp are common in saltwater riparian areas. Plant species tolerant of saline conditions, called halophytes, are also common along saline areas of the prairies and other arid lands. Desert salt grass (*Distichlis stricta*) occurs in saline soils of the Great Plains and is found along stream courses

Figure 2. Example of herb dominated riparian areas, which usually occur where woody vegetation is limited

and in the beds of intermittent ponds (Costello 1980). Brackish water areas may have a large variety of plant species present, including rice (*Zizania* spp), arrowhead (*Sagittaria* spp), bullrush (*Scirpus* spp), cattail, burweed (*Sparganium* spp), cow lily (*Nelumbo* spp), and many others (Appendix A). Mangroves (e.g., *Avicennia* spp, *Rhizophora* spp) are the only tree species tolerant of full-strength seawater.

Riparian plant growth form is greatly influenced by browsing and grazing. The natural succession of riparian plant communities includes the colonization and eventual dominance by woody species (see succession discussion below). Areas with heavy pressure on woody vegetation from wildlife species (e.g., beaver, elk) or farm livestock (e.g., cows, horses, sheep) can be stripped of woody vegetation and become dominated by herbaceous vegetation. Browsing limits regeneration of woody species (Kay and Chadde 1992) and stimulates shoot production of herbs (Allen and Marlow 1992). Intense grazing pressure will eventually eliminate herbaceous vegetation because of the removal of leaves and stems, as well as soil compaction and reduced root biomass. However, grazing in riparian areas can be managed to maintain woody vegetation that is critical for stream stability because of rooting depths deeper than those of herbaceous vegetation (Kovalchik and Elmore 1992).

The size, density, and aerial coverage of riparian plants in an area are dependent on the vegetation growth forms and physical dynamics of the site over time (Figure 3). Growth forms limit the size and density that vegetation can attain. Mature woody plants, for example, are generally larger and less dense than herbaceous vegetation. The physical dynamics of a site influence all three parameters. Small, young plants dominate recently disturbed areas. As vegetation

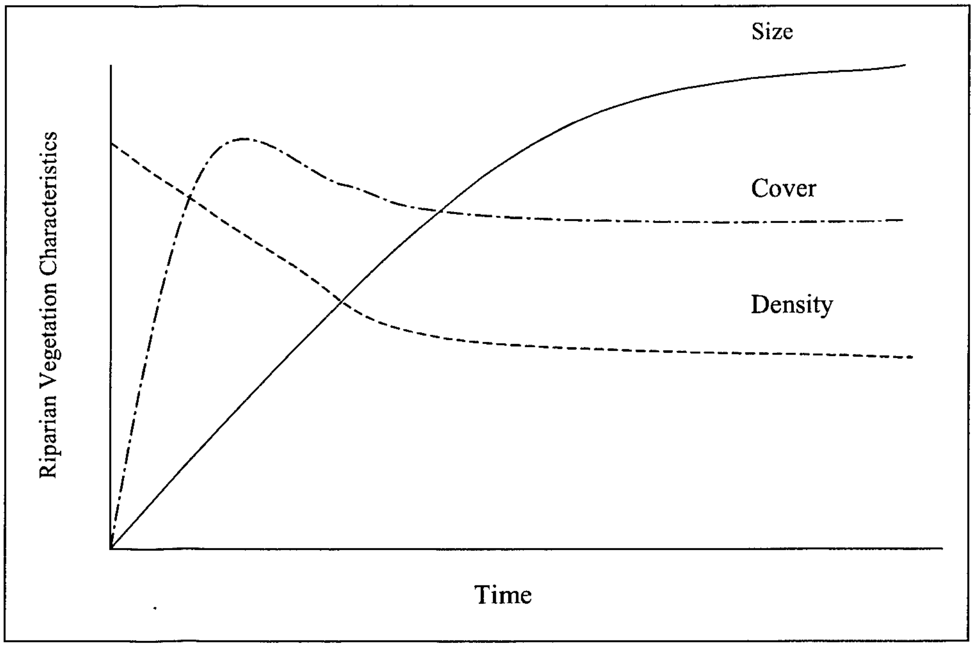

Figure 3. Changes in vegetation characteristics with time

matures following disturbance, they get larger -- some larger than others. Light becomes a limiting factor to the smaller plants which then die. Stem densities decrease. If the area becomes dominated by woody species, the height of the canopy will increase with time and maturation of the trees. The depth of the canopy will initially decrease as light becomes limiting at lower levels. The canopy will eventually stratify as understory, midstory, and canopy species reach maturity. Plants may rapidly cover up to 100 percent of an area soon after disturbance. Young, actively growing vegetation can maintain 100 percent canopy cover. The canopy usually begins to decrease coverage as plants mature and die out. Canopies are also opened when wind or some other force damages plants.

Basal area of vegetation also varies with precipitation. Progressing from areas with high to low precipitation, a transition zone is crossed between upland forests and grassland/desert ecosystems. For upland ecosystems, basal area of trees decreases with reductions in rainfall, and trees disappear at approximately 45 to 60 cm per year precipitation. However, abundant examples of robust stands of riparian forests are found in regions with less than 50 cm annual precipitation. This indicates that the aboveground structure of riparian vegetation is less dependent on amounts of precipitation than is upland vegetation (Brinson 1980). Large western riparian trees are capable of utilizing groundwater and are not so reliant on precipitation and surface water as are small trees and herbs (Flanagan, Ehleringer, and Dawson 1992).

Below ground structure

One of the most critical but least studied aspects of riparian vegetation is the root system. Roots contribute to many functions of riparian vegetation. Hydrology of riparian areas is affected by the increased infiltration of water along root channels and the depth to which roots can access water (Dunne and Leopold 1978). Substrate stability is increased by roots binding soil into aggregates, which are in turn broken up by the mechanical effects of the living roots and kept from coalescing into clods (Weaver 1968). Nutrients are transformed with oxygen transported into saturated soils via roots (Mitsch and Gosselink 1993). Roots anchor vegetation in place. Below ground fauna use roots for food. Roots, however, are particularly difficult to access and study, so much of the information regarding roots is indirect or anecdotal. Of importance in riparian areas is an understanding of the depth, density, and strength of roots.

In general, the larger the plant, the larger the root system. Tree root systems extend out roughly 1.5 times the canopy diameter. Flanagan, Ehleringr, and Dawson (1992) showed that large western riparian trees can access deep groundwater, whereas small individuals of the same species had relatively shallow root systems that can access only stream water and precipitation.

Depth of the root system is highly dependent on species characteristics and site limitations. Some species, called phreatophytes, have very deep root systems that can reach deep groundwater (see next section). Many species such as pine trees and members of the carrot family (Apiaceae) have taproots that extend straight down into the ground. Tap roots function for increased plant stability and the access of deep water and nutrients. It is the nonwoody fibrous roots, however, that are primarily responsible for uptake of nutrients and water. All plants have fibrous roots. Most fibrous roots are generally located in the top 30 cm of soil (Weaver 1968). Shallow fibrous roots can become very dense and effectively bind upper soil layers. Trees and shrubs develop networks of woody roots that extend deeper into the ground. This network of woody roots includes fibrous roots that in combination strongly bind soils into aggregates and provide sediment stabilization to much greater depths than fibrous roots alone. This is why trees and shrubs provide better shoreline stabilization in most cases than herbaceous species with relatively shallow roots (Figure 4).

Rates of evapotranspiration are related to the depth of plant roots relative to the capillary zone above the water table. Evapotranspiration rates become reduced as water tables recede and shallow rooted plants transpire less. Deeper rooted plants can tap water in the subsoil and continue to transpire at potential rates. Trees usually transpire more than grass because they are more deeply rooted (Dunne and Leopold 1978).

Phreatophytes are defined as plants that obtain water from the zone of saturation, either directly or through the capillary fringe (Meinzer 1927). The term is usually applied to deep rooted species that occur in arid riparian areas. Roots of salt cedar, an invasive phreatophyte in the Southwest, for example, have been excavated from as deep as 30 m. Excessive losses of water in water-limited areas have been attributed to high evapotranspiration rates of phreatophytes

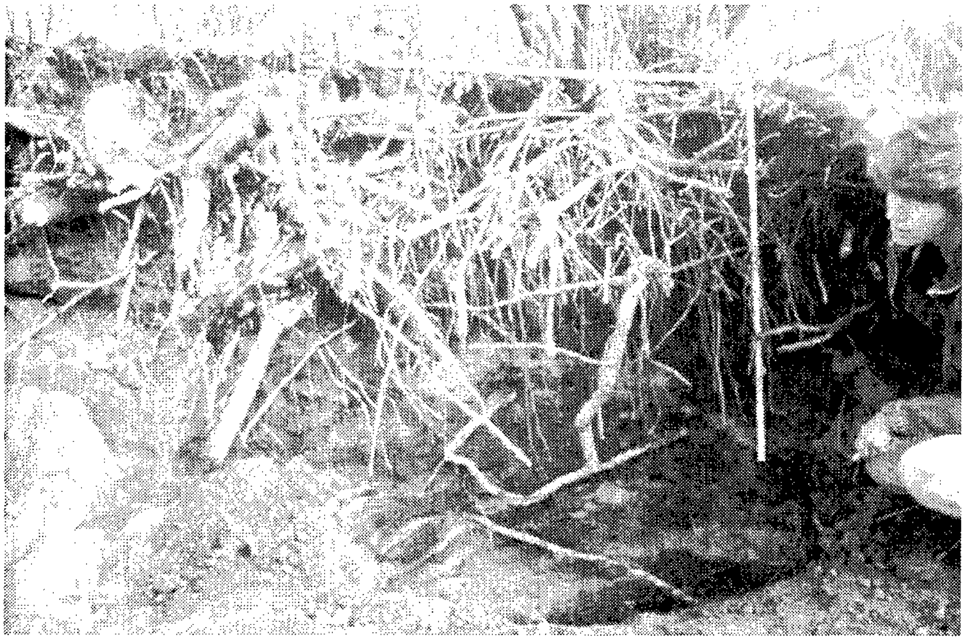

Figure 4. Shallow rooting depths of grasses are less effective at stabilizing banks than deeper rooted trees and shrubs

(Dunne and Leopold 1978). Management of phreatophytes to reduce water loss has included techniques such as plant removal, replacement with more shallow rooted species, lowering of water tables and anti-transpirants (Ritzi, Bouwer,and Sorooshian 1985, Stabler 1985). Phreatophyte management in different parts of the country has had mixed success, often with undesirable side effects such as loss of wildlife habitat and mass wasting (Dunne and Leopold 1978).

Distribution Patterns of Riparian Vegetation

The term riparian vegetation brings different things to mind for different people, often depending on whether they are from the east or west. The eastern portion of the country is generally moister than the western portion, where annual rainfall amounts are often much less than the evapotranspiration rates. In addition, riparian vegetation in high gradient, confined streambeds is much different in form and function than riparian vegetation in low gradient, alluvial systems. In general, riparian vegetation can be described in terms of type, zone, and landscape position.

Moisture gradients

The riparian corridors are described as having two gradients. The intrariparian continuum extends upstream from the mouth of the stream or river to the headwaters. Hypothetically, one can travel from the estuarine system upstream along perennial riverine systems, past confluences with other streams, proceeding to mesophytic habitats of intermittent reaches, and possibly

terminating in dry, desert xerophytic habitats of ephemeral streamcourses. The transriparian continuum extends across the hydrologic gradient from the water in the stream or river to the surrounding upland. In moving along this continuum, one sequentially transverses aquatic, wetland, and upland ecosystems.

There is a sharp contrast in these continua between different parts of the country. Intrariparian continua located in the more mesic eastern United States and Pacific Northwest often have perennial water from the source to the mouth of the river system. Conversely, some important western drainage systems, especially in the Sonora Desert and Baja California are entirely or essentially ephemeral from their origin to the Pacific or Gulf of California. As one proceeds from hydric to xeric conditions, the transriparian continuum becomes less distinct, and similarities decrease between the riparian vegetation and adjacent upland communities. For example, there is a clear distinction between riparian species along perennial eastern rivers and surrounding upland communities. In western washes or arroyos, however, plants and animals are generally shared with biotic communities of the surrounding uplands.

Riparian corridors can be complexes of aquatic, wetland, and upland habitats. These occur primarily in the eastern United States and the Pacific Northwest where floodplains are broad and morphologically complex (Wharton, Kitchens, and Sipe 1982). Aquatic habitats include the floodplain lakes, ponds, and sloughs. Wetlands occur throughout the terrestrial portion of the riparian corridor in areas associated with permanent aquatic habitats (e.g., on and behind river levees, oxbow lake fringes), as well as areas that are only periodically inundated by floodwaters. Wetlands also occur in riparian corridors along intermittent streams but are usually more limited in distribution to narrow fringes along the stream corridor. Upland habitats in the riparian corridor occur on relatively high ground relative to the river, usually on abandoned floodplain terraces or adjacent to uplands surrounding the geomorphic floodplain. Upland riparian habitats experience infrequent flooding for short durations.

Riparian corridors are characterized as areas with greater water availability than in surrounding landscapes. Upland areas within riparian corridors are characterized by increased soil moisture in comparison with adjacent uplands and by infrequent flood events. The vegetation may or may not differ in composition from the adjacent uplands but is usually denser, larger, and more productive.

Wetlands are defined as those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. Ecological processes in riparian wetlands are dependent upon inundation during annual cycles of river stage fluctuations. Some wetlands, however, are perched in the floodplain and upper elevations of the riparian corridor where their primary water sources are groundwater and precipitation (e.g., abandoned sloughs perched on old terraces). These wetlands are only indirectly influenced by the river through groundwater connections. While these

wetlands occur in the riparian corridor, they may not be considered to be riparian wetlands, because their ecological processes are not directly affected by the river.

There has been discussion among eastern and western riparian ecologists about whether all terrestrial areas within riparian corridors should be considered wetlands. In many cases, the western point of view that the definition of wetlands is based on moister eastern conditions; however, the term should encompass the relatively wet riparian corridors of the West. Even the xeric riparian habitats of southwestern deserts dominated by sahuaro cactus differ from the surrounding uplands because of the increased relative availability of water. Use of the term "wetland" in this report, however, is restricted to the definition given above. Many riparian corridors do not include wetlands, because they do not have adequate periods or frequencies of inundation to support hydrophytic vegetation or hydric soils.

It should be noted here that even though dredge and fill activities in many riparian areas are not regulated under Section 404 of the Clean Water Act (CWA) as being in wetlands, they may be regulated because they occur in other "Waters of the United States." The CWA specifically regulates activities in certain "Waters of the United States," including the following waters as defined in 33 CFR 328.3:

"... 1) all waters that are currently used, or were in the past, for interstate or foreign commerce, including all waters that are subject to the ebb and flow of the tide; 2) all interstate waters including interstate wetlands; 3) all other waters such as intrastate lakes, **rivers, streams (including intermittent streams),** mud flats, sandbars, wetlands, slough, prairie potholes, wet meadows, playa lakes, or natural ponds; 4) all impoundments of waters otherwise defined as waters of the United States as defined; **5) tributaries of waters identified in numbers 1-4 above;** 6) the territorial seas; and 7) wetlands adjacent to water listed in 1-6 above." (Bold added by author of this report).

This could be interpreted to mean that "Waters of the United States" exist where there is evidence of the presence of water at the surface (e.g., scouring, drift lines, etc.). "Waters of the United States," therefore, can extend upland as well as upstream of wetlands. It is recommended that the local office, U.S. Army Corps of Engineers (USACE), be contacted for a Section 404 determination prior to any dredge and fill operations in riparian corridors.

Riparian wetlands are critical areas for the health of the riparian corridor and downstream ecosystems. Riparian wetlands are often highly productive systems that support diverse and abundant wildlife (Wharton, Kitchens, and Sipe 1982). In addition, riparian wetlands provide valuable functions for society (Taylor, Cardamone, and Mitsch 1990, Brinson et al. 1995). Floodwaters are stored and slowly released from riparian wetlands, ameliorating flood intensities in downstream areas. Many nutrients, toxins, and sediments are retained or transformed in wetlands, providing cleaner water. Moreover, the beauty of the flora and fauna of these areas cannot be duplicated elsewhere.

The most well studied riparian wetlands are the bottomland hardwood forests of the eastern and central United States. In contrast with other types of wetlands, these wetlands are often adjacent to gaged rivers and streams, and relationships between the river water level fluctuations and ecology of the areas have been described (Clark and Benforado 1981, Wharton, Kitchens, and Sipe 1982). After concern about extensive losses of these wetlands to agriculture and river management, much work has been done to understand effects of cumulative impacts on bottomland hardwood forests (Gosselink, Lee, and Muir 1990).

Huffman and Forsythe (1981) described several characteristics of bottomland hardwood forests that distinguish them as wetlands:

a. The habitat is inundated or saturated by surface or groundwater periodically during the growing season.

b. The soils within the root zone become saturated periodically during the growing season.

c. The prevalent woody plant species associated with a given habitat have demonstrated the ability, because of morphological and/or physiological adaptation(s), to survive, achieve maturity, and reproduce in a habitat where the soils within the root zone may become anaerobic for varying periods during the growing season.

Characteristics of these wetlands are closely tied to frequency and duration of flooding (Figure 5). Swamps are inundated nearly 100 percent of the time. They occur at low elevations adjacent to the channel and in perched depressions that retain water after floodwaters recede. These forests are typically dominated by only two tree genuses (*Taxodium* spp and *Nyssa* spp). Hardwood wetlands located at slightly higher elevations than swamps are inundated for shorter periods of time and less frequently. These wetlands have higher plant species richness, with water-tolerant oaks, maples, sweetgum, ash (*Fraxinus* spp), and many other hardwood trees in the canopy. Hardwood wetlands at high relative elevations are inundated less than one-half of the years and only for short periods at a time. These are marginal wetlands that are transitional with upland areas (Clark and Benforado 1981).

Functions of riparian vegetation

Many of the functions that riparian vegetation contributes to bottomland hardwood forests change with elevation above the river (Figure 5). As will be elaborated in later sections, much of the value of riparian vegetation is food production, nesting, and refuge areas for wildlife. Medium and high zone bottomland hardwood wetlands generally have higher plant species richness and primary productivity relative to other zones, but they do not necessarily support more wildlife. Each zone has value for different species. Swamps and lower bottomland hardwood wetlands, for example, support more aquatic species than terrestrial species. Higher zones support more terrestrial species. Together the

different wetland zones form a highly diverse and productive ecosystem (Mitsch and Gosselink 1986).

Physical and chemical functions of bottomland hardwood wetlands are also closely tied with river level fluctuations (Figure 5). Sediment deposition and anaerobic biochemical transformations predominate at lower elevations as a result of the longer and more frequent periods of inundation. Most biologically mediated chemical transformations occur at lower and medium bottomland hardwood zones, because there is ample moisture and organic matter on the forest floor to serve as a substrate for respiration (Taylor, Cardamone, and Mitsch 1990).

In addition to the habitats presented above, the riverine littoral zone should be identified as having particular importance. Aquatic river-edge environments are outstanding examples of ecological boundaries, although they have received little attention from lotic and terrestrial ecologists. The riverine littoral zone provides comparatively calm water and stable sediments, with habitat structure provided by rocks, snags, plants, and bank irregularities. The littoral boundary is a key part of the corridor, being a zone of concentrated physical and biological diversity and a resource for both riverine and terrestrial communities. It is particularly vulnerable to patterns of disturbance, particularly changes in water level (Walker, Thomas, and Sheldon 1992).

The riverine littoral zone is characterized in most areas as the river bank, from the edge of the water to the top of the bank. This may include active bars, shelves, and islands within the channel (Hupp and Osterkamp 1985). Upper portions of the bank are usually forested with species common to swamps or lower riparian habitats. Overhanging vegetation, exposed roots, rocks, and debris provide excellent habitat structure along the mid- and upper portions of the bank. The lowest portion of the bank and shelves are frequently barren sediments that are exposed at low river stages.

This zone is unique because it provides constant contact between the aquatic and terrestrial portions of the riparian corridor. It is therefore directly affected by river level fluctuations and currents. High river stages inundate the entire littoral zone and provide fish and other aquatic or amphibious species access to upper littoral zone resources. Low river stages remove access to refuge, food, and spawning areas for aquatic and amphibian animals as the higher elevation areas become exposed. Periods of low water are necessary, however, to allow the terrestrial plants and animals to recover from the inundation as part of the annual cycles that make these areas so valuable.

Habitat value provided in the vegetated portions of the riverine littoral zone is important for several reasons (Sweeney 1993). Overhanging vegetation shades and cools the water and surroundings, helping provide thermal refuges in an otherwise exposed and stressful environment. Roots and debris are colonization sites for algae and macroinvertebrates. Organic matter is eaten by macroinvertebrates. Many organisms take refuge from predators and currents among the roots, rocks, and other structures. In addition, roots form tight networks over the bank soil that keep them from sloughing into the river, providing stable habitats and good water quality. Stable banks provide nesting

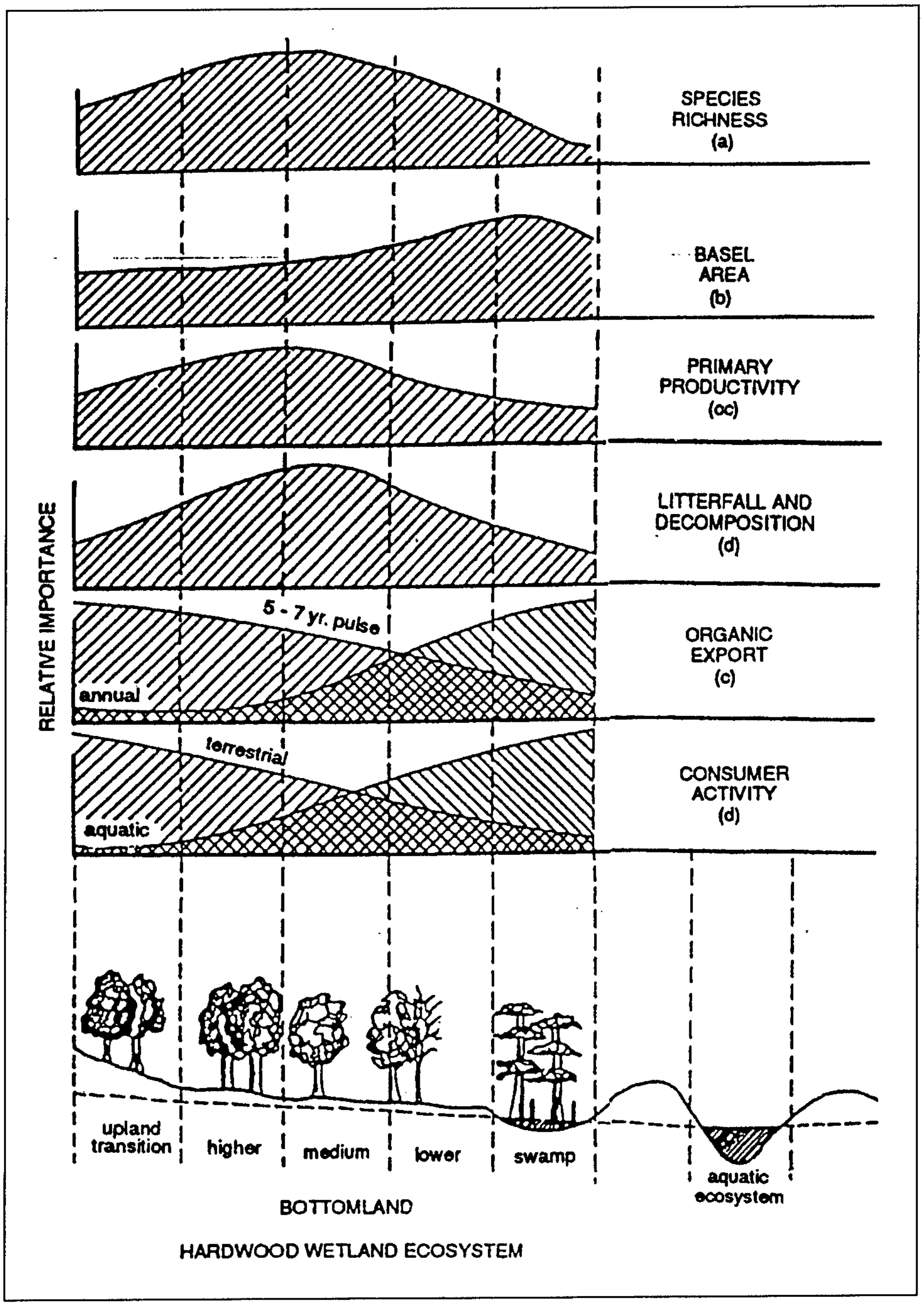

Figure 5. Characteristics of bottomland hardwood forests across a flooding duration and frequency gradient (after Taylor, Cardamone, and Mitsch 1990)

sites for many vertebrate species, including kingfishers, swifts, and mink. Habitat value is apparently highest when the river inundates plants, roots, debris, and other structures, linking aquatic life with high-quality terrestrial resources along these corridors.

Aquatic habitats are generally differentiated from wetlands as those areas that are permanently inundated to depths greater than 2 m, generally the depth beyond which emergent plants can grow. Riparian aquatic areas include oxbow lakes, sloughs, the main channel, and other permanently inundated areas. Although submerged vegetation can grow in these habitats, this vegetation is not riparian vegetation and is beyond the scope of this report.

Fluvial geomorphic landforms

Associated with the transriparian moisture zones described above are the vegetational distribution patterns on fluvial geomorphic landforms common to many rivers. The type of landforms associated with alluvial rivers depends on the constancy of stream flow and position in the floodplain (Figure 6). Alluvial rivers in the East are perennial and have complex mosaics of depositional bars, active-channel shelves, floodplains (including levees, flats, ridges, swales, and oxbow lakes), and terraces (Wharton, Kitchen, and Sipe 1982, Hupp and Osterkamp 1985). Lush riparian vegetation in these areas is distributed among these landforms in different species associations, ages, and structures. Western river floodplains can be equally complex; however, the arid climate limits development of extensive floodplain vegetation. The extent and complexity of the fluvial landforms decreases with decreasing basin size and water availability as the result of lower flows and energy to carry alluvium. Vegetation within the intrariparian gradient, therefore, generally becomes less complex in composition and distribution towards the headwaters. Appendix A lists riparian species and the fluvial geomorphic zones where they are typically found.

Active channels include all areas within banks, including point bars and shelves. The plant species in active erosional/depositional channels are often capable of rapid colonization and are relatively short-lived. These species are often widely distributed because their seeds are small and wind-dispersed (Hupp and Osterkamp 1985). The life history of these species depends on continual renewal of open, moist areas for regeneration. In the East, sycamore (*Platanus* spp), cottonwood, willow, and elm (*Ulmus* spp) are the most common genera in these areas (Hupp and Osterkamp 1985). *Salix lasiandra*, *Populus trichocarpa*, and *Alnus rubra* are common trees along active perennial channels in British Columbia, where there are also marsh species such as *Typha latifolia*, *Glyceria grandis*, and *Puccinella pauciflora* (Teversham and Slaymaker 1976). In the arid West, Freemont cottonwood, willow, sycamore (*Platanus wrightii*), alder (*Alnus oblongifolia*) and ash (*Fraxinus pennsylvanica velutina*) are common trees. Seep willow (*Baccharis glutinosa*) and watercress (*Rorippa nasturtium-aquaticum*) were common along flowing streams in Arizona (Glinski 1977). Mesquite (*Prosopis* spp), catclaw acacia (*Acacia gregii*), ironwood (*Olneya tesota*), and blue paloverde (*Cercidium floridum*) are common within xeroriparian corridors of the sub-Mogollon desert region.

Composition and complexity of floodplain vegetation depends on the size and geomorphic complexity of the riparian corridor. Bottomland hardwoods, for example, can be extensive such as in the Mississippi Delta or more restricted to

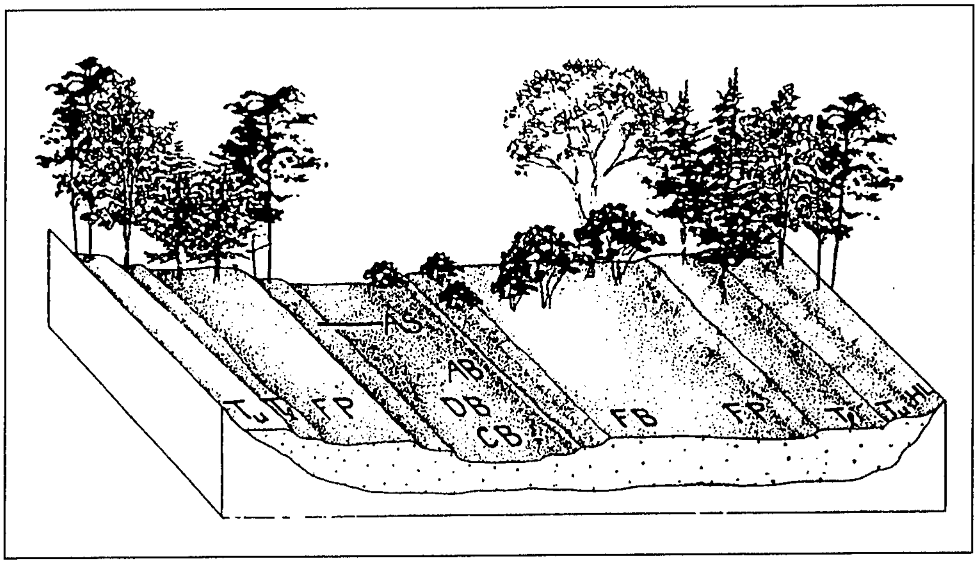

Figure 6. Landforms associated with alluvial rivers – hillslope (HL), upper and lower terraces (T), floodplain and bank (FP and FB), channel shelf and bank (AS and AB), depositional bar (BD), and channel bed (CB) (after Hupp and Osterkamp 1985, ESA 1985)

narrow bands along smaller rivers. Elevation gradients within floodplains associated with ridges and swales, oxbows, and other abandoned riverine features affect the duration and frequency of inundation an area receives. Plant species composition is directly determined by these hydrologic patterns (Bell and Johnson 1974, Teversham and Slaymaker 1976, Robertson, Weaver, and Cavanaugh 1978, Wharton, Kitchen, and Sipe 1982, Theriot 1993). Similar to the relationship of eastern bottomland hardwood vegetation with hydrology described above, there is a correlation of tree and shrub species in British Columbia with flood frequency. The frequency of five species, *Thuja plicata* (red cedar), the shrubs *Viburnum pauciflorum*, *Cornus stolonifera*, (red-osier dogwood), and *Spirea douglasii* (hardback), as a good predictor of flood frequency of the Lillooet River (Teversham and Slaymaker 1976).

Western riparian ecologists do not report similar variations in distributions of floodplain vegetation species with frequency and period of inundation along a transriparian gradient. Composition of western riparian vegetation varies with depth to the water table. Species composition changes with distance from the stream because rooting depths of plant species becomes limiting with depth to the water table (Segelquist, Scott, and Auble 1993). In these arid areas, the distinctions in vegetation are made between ephemeral, intermittent, and perennial streams along an intrariparian gradient.

Both intermittent and perennial western rivers have floodplains. Intermittent western streams and rivers support a higher proportion of grasses and shrubs than trees. Sacaton grass (*Sporobolus airoides*) and scrub species dominate upper alluvial valley of Sonoita Creek, Arizona, with scattered individuals of mesquite (*Prosopis juliflora*), walnut (*Juglans major*), Freemont cottonwood, and sycamore (*Plantanus wrightii*). Farther down the Sonoita Creek where flow becomes

perennial, there is a near-continuous forested belt of cottonwood, sycamore, willow (*Salix gooddingii*), ash (*Fraxinus velutina*), and walnut trees. This forest is bordered frequently by mesquite and hackberry (*Celtis reticulata*). These forest floors are covered with annual and perennial grasses and forbs. Velvet mesquite (*Prosopis velutina*) forms closed-canopy forests together with other riparian trees and shrubs including netleaf hackberry (*Celtis reticulata*), walnut, and lotebush (*Zizphyus obtusifolia*) in perennial river floodplains in the Sonoran Desert (Stromberg et al. 1993). Tree species richness varied in a bell curve fashion with flood size in the Verde River watershed, Arizona, with the greatest richness occurring at streams with intermediate flood magnitudes (Stromberg et al. 1993). Bloss and Brotherson (1979) found an increase in floodplain plant species diversity with increased available moisture near an ephemeral stream in comparison with adjacent slope communities in central Arizona.

Many floodplain species are wide spread, with a wide moisture-tolerance range. In the east, for example, red maple, sweetgum, and water oak have very broad distributions within floodplains. Velvet mesquite is widely distributed within the Sonoran Desert from xerophytic riparian washes with ephemeral flow to perennial river floodplains (Stromberg et al. 1993). Saguaro cactus is generally more abundant and larger in xerophytic riparian areas in comparison with individuals in upslope areas.

Terraces are floodplain surfaces that became hydrologically abandoned with downcutting of the river to lower elevations or deposition of sediments usually associated with extreme events. Occurrence of riparian vegetation is not consistently reported in terms of presence on terraces versus simply high elevations within the floodplains. Distributions of vegetation have been reported here in terms of relative elevation above the present river level. The distinction becomes important, however, when presenting distributions of vegetation along rapidly eroding rivers and streams. Existing riparian vegetation becomes isolated from surface water and groundwater in these areas, and frequently dies from dehydration (Bryan 1928). New riparian vegetation becomes established at lower elevations near the river level as the channel broadens and relatively stable shelves develop. This process occurs naturally over long time periods. Fonda (1974) described different tree communities among river terraces of the Hoh River of the Olympic Peninsula, Washington, that differed in age from active to over 750 years old.

Stream gradients

The influence of stream gradients on the riparian vegetation composition and structure depends primarily on the watershed configuration. For example, high gradient streams (>3 percent slope) are often constricted within steep valley walls and dominated by tree species. The streambed is composed of bedrock, boulders, cobble, or gravel that form falls and cascades interspersed with small pools. Flood events are intense and short in duration. Debris carried downstream during floods is a major type of disturbance for riparian vegetation. Trush, Connor, and Knight (1989) found lower densities of trees in active channels of steep

entrenched streams than in lower gradient streams within floodplains in coastal California. They suggest that the increased energy in the entrenched streams during floods was detrimental to tree establishment and survival. Baker (1989) suggests that trees dominate riparian areas along high-gradient streams rather than the shrub-like willows found in low-gradient systems of western Colorado, because trees are simply more resistant to the destructive action of large gravel and boulders carried in floods.

Trees carried into streams can become lodged across and within the channel. The resulting accumulations of woody debris provide valuable in-stream functions such as dissipation of energy, storage of sediment, and provision of habitat. Forest management affects channel morphology in several ways. Removal of large woody debris from channels reduces sediment storage and eliminates the local hydraulic variability associated with the obstruction. Excessive input of coarse sediments from the surrounding watershed can smooth the channel gradient by filling pools. Land uses that change the natural amounts of sediment or water contributed to the streams disrupt the balance of sediment input and removal. Loss of in-stream habitat diversity by any of these practices may reduce or change the fish species found in a stream reach.

Plant communities generally undergo little change along stable streams such as riffle-pool or entrenched meadow streams. These streambeds change little over time, because the water and sediments are effectively conveyed through the reach with little erosion or deposition (Rosgen 1995). There is little disturbance to the vegetation and no creation of new habitats for colonization. These plant communities are mature and resilient to flood events.

In contrast, plant communities along low-gradient, unconfined alluvial streams vary in maturity depending on the time since establishment following deposition on point bars (Wharton, Kitchens, and Sipe 1982, Hupp and Osterkamp 1985). Erosion and deposition are natural in these streams as the streambed constantly changes position within the floodplain. Mature vegetation is lost with erosion of the outside bends of meanders as areas for colonization are formed on the inside bends. Floodplain vegetation in this type of system occurs in a continuum of successional stages, from newly colonized point bars to mature forests.

Riparian Ecological Processes

Since riparian settings are interfaces between terrestrial and aquatic systems, ecological processes in these settings are dependent on the dynamics of both the associated uplands and the streams. Ecological processes such as plant succession and response to natural disturbances occur in most types of ecosystems. Natural rates and direction of these processes in riparian habitats, however, are overridden by flooding, erosion, and deposition events associated with streams. In addition, disturbances from uplands such as debris slides, fire, and grazing affect riparian habitats.

Succession

The maturation process of natural plant communities is termed "succession" (Drury and Nesbitt 1973) or community development (Niering 1987). Plant communities develop from two starting conditions. The first type of development, often called primary succession, takes place on newly formed areas where no plant community as ever occurred before, such as on volcanic flows, that eventually support diverse, mature plant communities. In this situation, community development can be extremely slow. Soils must form. Colonization by microbes, plants, and animals is slow at first as a result of the extremely harsh and stressful conditions. Establishment of riparian plant communities on newly formed point bars can be considered to be primary succession.

Plant communities, however, more commonly develop following a disturbance that is severe enough to set community development back to earlier developmental stages or to a point at which the system must develop anew (Drury and Nisbet 1973). This second type of development is called secondary succession. An example of secondary succession is the development of a forest over many years after an agricultural field is left fallow. In this situation, plant community development is more rapid. Soils capable of supporting plants are already formed. Site conditions are not as harsh and colonization is rapid; annual plant species are present in the first year. The types of plants and animals present will change over time. For example in classical old field succession, annual and grass species are often the first dominant plant species as a site develops. As colonizing plants become established, conditions for plant growth are improved and different species become dominant that are not tolerant of the harsher site conditions. Shrubs may dominate early and middevelopmental stages. Trees begin to colonize a site during early succession but do not dominate the site structurally until mid-to-late successional phases. Eventually, the rate of new species introductions decreases, the plants on site regenerate themselves, and the species composition stabilizes. At this point, the community is considered to be a in a "climax" or steady state (Odum 1975, Neiring 1987). Many cases of riparian community succession can be considered secondary succession, because site conditions retain some of the components of the degraded system after the disturbance.

Succession of riparian plant communities is integrally related with the associated stream dynamics. It is the sequence of floods and shifting sediments that create new surfaces and deliver seeds of colonizing species. Seeds of many riparian species such as maples and willow are carried by water and deposited on newly exposed areas. Animals deposit seeds from fruit they have eaten such as mulberry and elderberry (*Sambucus* spp). Colonizing plants may also result from clumps of plants that have broken off eroding areas and subsequently stranded on bars downstream (Bliss and Cantlon 1957).

There are relatively few plant species that are capable of becoming established on newly developed bars because the environmental conditions are often very harsh. With little organic matter or soil development, the exposed bars dry rapidly following falling river levels. Seeds and new seedlings are often desiccated and die before root systems are developed that can reach the groundwater (McBride

and Strahan 1984). Ware and Penfound (1949) describe bars of the South Canadian River in central Oklahoma as being very unstable habitats for plant growth. Annual floods inundate and destroy much of the existing vegetation. In addition, as the bars dry out, winds blow sands that may completely cover seedlings, uncover roots, or undermine plants and blow them away. The point bar colonizing species share several adaptations that ensure establishment of floodplain forests despite the vagaries of the river. These adaptations include an extended period of seed dispersal, large numbers of seeds, and plumes that carry the seed on the water and become entrapped in sands (Noble 1979).

In spite of the harsh conditions, there is often a fairly dense cover of plants on newly deposited bars. Willow, cottonwood, and alders are the most common tree species that colonize newly developed bars in many kinds of streams. Cottonwood (*Populus deltoides*), sandbar willow (*Salix interior*), and salt cedar (*Tamarix gallica*) are common colonizers on bars of the South Canadian River in central Oklahoma (Ware and Penfound 1949). Various willow, balsam popular, and mountain alder (*Alnus incana*) are the primary tree-colonizers on newly formed areas of the Beatton River in northeast British Colombia (Nanson and Beach 1977). Black willow is a primary colonizer of depositional bars of eastern rivers (Wharton, Kitchens, and Sipe 1982, Hupp and Osterkamp 1985). In riparian communities of the arid Southwest, the same species that colonize depositional bars ultimately constitute the mature community (Lowe 1964). Cottonwood (*Populus fremontii*), willow (*Salix bonplandiana, S. gooddingii*, and others), sycamore (*Platanus racemosa wrightii*), ash (*Fraxinus velutina*), and walnut (*Juglans microcarpa major*) are termed the "big five" in reference to widespread riparian trees in the Arizona lowlands (Johnson, Bennett, and Haight 1989). However, mesquite, catclaw acacia (*Acacia greggii*), ironwood (*Olneya tesota*), blue paloverde (*Cercidium floridum*), and desert willow (*Chilopsis linearis*) dominate xerophytic riparian communities along desert washes (Johnson, Bennett, and Hought 1989). See Appendix A for additional woody species that colonize in river and stream channels.

Grasses and herbs are often among the colonizing plants on depositional bars, but they tend to comprise a minor component of the total biomass, which is dominated by woody species. Because they are not structurally resistant to the stress of flood flows, seedling herbs are often uprooted and washed away if flooded too soon after germination. Herbaceous species tend to become established, therefore, on higher or protected portions of depositional bars or following the establishment of shrubs (Bliss and Cantlon 1957). Alternatively, if depositional bars are adjacent to established herbaceous communities, existing plants may be able to spread vegetatively onto the new bars and rapidly establish robust vegetation. There are many desirable species capable of vegetative spread. However, common reed and cattails are examples of nuisance species with horizontal underground stems that readily spread vegetatively. These are very aggressive species that can become nuisances along many waterways because of their dense growth and minimal wildlife habitat value.

Once established, the vegetation on depositional bars provides resistance to flood waters, slowing the velocity and increasing further deposition. Elevation of

the bar surface increases as sediments accumulate around stems. All plants contribute to the resistance but woody perennials are most important (Ware and Penfound 1949). Deposition amounts eventually decrease as the bar becomes inundated less frequently. Decreased periods of inundation and reduced current velocities over the bar result in improved conditions for establishment of additional species. For example, balsam poplar initially becomes established on young ridges of bars in river channels of the Beatton River in British Columbia. Following an abrupt decline in sedimentation on surfaces approximately 50 years old, white spruce rapidly colonize the bare mineral soil beneath the poplar canopy (Nanson and Beach 1977). Further increases in elevation with sedimentation and organic matter accumulation allow continued decreases in period and frequency of inundation and additional species to survive. Surviving willow trees in interior portions of the diverse bottomland hardwood forests of the Southeast are evidence of historic river movements.

The degree to which a plant community will develop and change over time, since establishment on a river bar, depends on the area and behavior of the river. The lack of succession from colonizing species in the arid Southwest forms one end of a continuum. Floods that destroy riparian forests recur on roughly 100-year cycles in the Southwest, which may be adequate to retard succession (Johnson, Bennett, and Haight 1989). Fonda (1974) described a succession of forests on terraces of the Hoh River, Washington. Each successional stage is dominated by one or two tree species. The very diverse mature Southeastern bottomland hardwood forests do not resemble the colonizing plant community at all and define the opposite end of the continuum. These forests occur in river systems that are constantly changing shape (Wharton, Kitchen, and Sipe 1982). While some newly colonized areas are destroyed by floods, many are eventually abandoned by the river as it changes course. Although floods still occur in the abandoned areas, succession can proceed under less stressful conditions.

Just as stable river channels have areas of erosion and deposition, stable riparian plant communities have areas of regeneration and loss. Ideally, as point bars are creating areas for colonization, eroding banks are removing equal areas of mature communities in a dynamic equilibrium.

Responses to disturbances

Disturbances are common forces on ecosystem dynamics. As systems develop toward a steady state, disturbances of various types and levels of intensity occur that can alter the vegetation development process. Disturbances can affect the types and structures of plant populations in a community by:

a. Changing species mixtures by eliminating propagules (i.e., seeds and vegetative propagules) of some species.

b. Creating harsh conditions for seed germination or vegetative growth for some species or enhanced conditions for others.

c. Reducing competition for available resources by removing dominant vegetation.

d. Altering growing conditions that change species survival, growth, and reproduction rates, hence shifting species dominance and structure.

Ecosystems that are regularly subjected to low-intensity disturbances (e.g., fire in southeastern forests and inundation in wetlands) have characteristic species associations that are adapted to these conditions. If the communities are mature, there is little species turnover after a low-intensity disturbance event, and the species complement remains relatively steady. The disturbance acts to reduce competition from species that would invade in the absence of the disturbance (such as a pine forest developing into a mixed hardwood forest in the absence of fire or a wetland forest developing a more mesic mixture of species when drained). Disturbance is often understood as a discrete event in time that disrupts ecosystem resources, availability of substratum, or the physical environment (Pickett and White 1985). It can be argued that "disturbance" is a misleading term used in this manner, that fire and water, for example, are natural forces in the landscape that are necessary to maintain certain types of communities. Regardless of the term used, the absence of frequent, low-intensity periodic events, such as fire and flooding from areas where they naturally occur, results in shifts in ecosystem characteristics.

High-intensity natural disturbances usually occur with less frequency and are more catastrophic to ecosystems than low-intensity disturbances. Intense disturbances can remove all vegetation and set back succession to the initial developmental stages. For example, prolonged flooding creates conditions beyond the tolerance threshold of many wetland species, and they eventually succumb. As described above, fallow agricultural fields have been subjected to intense landuse practices that remove all natural vegetation. The resulting successional plant communities develop and change with time.

Disturbances help maintain a dynamic mosaic of plant communities in different developmental stages within a landscape. Riparian systems of the arid Southwest, for example, are renewed by intense episodic floods that remove portions of established forests and create new areas for regeneration. In addition, disruption caused by fires, pulses of sediment, or drought is extensive but not complete. Communities are often adapted to regenerate from undisturbed areas in the riparian corridor (Hect 1993). Rather than being detrimental, the increased diversity within landscapes is often beneficial. Wildlife value, for example, is often increased as different habitats are created and edges between habitats are increased that support different species. The dynamic mosaics of these landscapes are the natural and desirable state of the riparian system.

Hydrologic conditions are primary factors in determining the distribution and functions of riparian vegetation (Brinson et al. 1981, Mitsch and Gosselink 1993). By definition, surface hydrology of riparian areas is driven by flows in streams and rivers (Brinson 1993). Establishment and growth of vegetation in most riparian areas is limited by inundation or flow energy of surface water. Vegetation in riparian areas that receive only short periods of overland flow,

however, may be further limited by availability of groundwater. In arid areas in particular, rooting depths of riparian vegetation must be adequate to reach groundwater a sufficient period of the year to sustain the plants. In contrast to riparian vegetation in humid regions, riparian vegetation in arid regions is limited to areas where groundwater is available rather than being limited by too much water. It is, therefore, important to understand groundwater hydrology of riparian areas as well as surface water hydrology.

Hydrologic regimes in wetlands are usually characterized by the depth, duration, frequency, and season of inundation by surface water or saturation by groundwater. Depth and duration of flooding determine the availability of oxygen to plant roots by creating a barrier to oxygen diffusion into saturated soils. The longer an area is inundated, the lower the oxygen content of the soil becomes because plants and soil microbes utilize it in respiration. When the oxygen concentration is low, respiration pathways switch from aerobic to anaerobic (i.e., fermentation) and energy becomes very limited. Toxic by-products of anaerobic respiration accumulate in the soil and conditions become stressful for most plant life (Mitsch and Gosselink 1993). Many plants are not tolerant of low oxygen conditions and consequently are not capable of surviving in flood-prone wetlands (Whitlow and Harris 1979). Wetland plants have adaptations that allow them to either tolerate short periods of low oxygen or oxygenate their roots (Kozlowski 1984a,b). Floodplain areas that experience long periods of inundation have a suite of species that are more flood-tolerant than areas that experience short periods of inundation (Wharton, Kitchens, and Sipe 1982).

Vegetation is more tolerant of flooding if at least part of the plant remains above the water. The emergent portion of the plant is capable of accessing oxygen and continuing photosynthesis to provide energy for respiration. Plants that are completely submerged do not have much energy available for growth or maintenance. In addition to limiting oxygen, depth of water, therefore, has a direct influence on the survival of flooded vegetation. This is illustrated, for example, in floodplain forest vegetation that is typically comprised largely of trees with little groundcover in areas that experience long periods of deep inundation. Shrubs and vines become more common as flooding depth decreases. And finally, grasses and herbs become abundant in the ground cover of floodplain forests that experience relatively short periods of shallow inundation.

Frequency of inundation influences plant distributions because the plants must have a period of recovery between flooding events to tolerate conditions at a site. In addition to reduced growth rates while flooded (Young, Keeland, and Sharitz 1995), plants can be damaged or silt can be deposited on the leaves, providing further stress. Frequent inundation stresses most plants beyond their capability to repeatedly recover.

In riparian areas that are not bordered by wetlands, the depth and duration of surface inundation or soil saturation is not necessarily adequate to produce such low oxygen levels that plant growth is limited. In these areas, groundwater hydrology primarily determines the distribution and functions of riparian vegetation. The rate and depth of groundwater decline affect plant establishment and survival. As seeds are deposited on newly exposed, moist surfaces, they

absorb water, germinate, and produce the first root. If groundwater declines too rapidly for the root growth to maintain contact, the seedling cannot survive. Segelquist, Scott, and Auble (1993) showed that plains cottonwood seedling survival was highest under slow groundwater drawdown rates and declined significantly with faster drawdown rates. The groundwater usually is sufficiently close to the surface to support different vegetation in riparian zones from the adjacent uplands. Even in dry arroyos of the arid Southwest, more moisture is available in the riparian area than in adjacent uplands, and there is a clear distinction between riparian and upland vegetation (Anderson and Ohmart 1975).

Vegetation in individual riparian systems reflects in part the characteristic groundwater and surface water hydrologic regimes of the site. The vegetation becomes established, survives preceding hydrologic events and is likely to be able to tolerate future events in the system because there is a certain amount of predictability of water behavior based on basin characteristics. All else being equal, patterns of water delivery are not likely to change radically over time.

The variability of hydrologic regimes, however, must be recognized and planned for. "Normal conditions" are difficult to define. Hydrographs vary widely on daily, monthly, and annual bases. Determination of hydrologic conditions based on average flows and season of duration aids in understanding the general conditions to which plants will be subjected.

Extreme events more commonly determine the vegetation distribution and function. For example, a 10-year return flood (368 m^3s^{-1}) occurred in the Hassayampa River, a perennial stream (0.1 m^3s^{-1}) within the Sonoran Desert. An average of 8 cm of sediment was deposited on the floodplain, with maximum deposition (to 0.5 m) on densely vegetated surfaces. Native riparian vegetation showed resistance and resilience to the flood disturbance. Survivorship corresponded to floodplain elevation. Cottonwood and willow plants on high floodplains (e.g., *Prosopis velutina* trees and saplings and *Populus fremontii* and *Salix gooddingii* trees) had low mortality. On low floodplains where water was less than 2 m deep, 40 percent of *Populus* pole trees died. Although some adults died, the same plant species maintained populations in the area. Seedlings of cottonwood and willow established abundantly after the flood along overflow channels and main channel sediment bars, contributing to age-class diversity for these episodically recruiting species. The exotic species salt cedar (*Tamarix pentandra*) had greater mortality and lower postflood recruitment compared with the native species. Shrub and herbaceous species largely recovered via vegetative regrowth and spread (Stromberg et al. 1993).

Changes in hydrologic regime result in changes in the associated riparian plant communities. Bryan (1928) described hydrologic changes in the arid Southwest through the 19th century, some of which were natural and some man-induced. There was a general decline in groundwater level and loss of the vegetation associated with moist conditions. For example, entrenchment of the Arivaca Creek, a tributary of the Santa Cruz River in Arizona, destroyed the springs among the bulrushes, the swamps, and ponds that once existed. Groundwater pumping in the karst topography of the Florida peninsula has led to

a shift of plant species in nearby wetlands to those more characteristic of upland conditions (Rochow 1985).

Loss of groundwater is relatively slow and the vegetational response may not be obvious in the short term. Impoundments, however, create abrupt and radical changes in hydrology that have dramatic affects on riparian vegetation. Harms et al. (1980) found increasing rates of mortality of floodplain trees with depth of inundation within 2 years of impounding the Oklawaha River in Florida. Species richness was reduced even where effects of flooding were minimal in the upper reaches of the reservoir. Plant communities downstream of impoundments are also affected by altered hydrology. Reduced flooding in dam-controlled streams permits plant life to colonize streambanks and shift to more mesic species associations. Flood-induced mortality of perennial riparian plants was high with regulated releases, with significant differences in mortality rates among plant species of the Colorado River corridor downstream of the Glen Canyon Dam (Stevens and Waring 1985).

Stream current energy experienced by riparian plant communities in terms of velocity, depth of flow, local shear, and turbulence intensity can be a strong organizing force due to the potential destruction of existing plants, erosion of substrates, and deposition of sediments. As discussed above in relation to adaptations of riparian plants, plants adjacent to streams can be subjected to high rates of flow during floods that can break or remove plants altogether. Plants such as willow that minimize breakage by deforming with flows and are capable of rapid vegetative recovery are at an advantage for survival in riparian corridors.

Types and amounts of particles transported by streamflow affect the relative energy riparian vegetation will experience as well as the availability of regeneration sites. It is surmised that trees dominate riparian vegetation along high-gradient streams, because they can tolerate the force of being hit with large rocks. There is relatively little erosion of substrates along constricted, high-gradient streams with rock beds, however, and loss of riparian vegetation is mainly a result of stream energy or erosive forces initiated in adjacent uplands (e.g., debris slides). Erosion and deposition of sediments resulting from stream currents become more important for the distribution of riparian vegetation in lower-gradient streams with erodable bed material.

Local scour around plants is a natural phenomenon in riparian systems. Erosion destabilizes plants by removing the structure in which the plant is rooted. If too much sediment is eroded from around plant roots, the plant can no longer support itself upright. A certain amount of erosion is tolerable. However, the plant dies if so much of the root system is exposed that there is not adequate water and nutrient uptake.

Historical riparian plant communities along the Platte River in Nebraska were maintained as herbaceous communities by the dynamics of alluvium with annual floods and the lack of woody species to colonize stream banks (U.S. Fish and Wildlife Service 1981). Tree species were made available for colonization by pioneers planting tree claims under the Timber Culture Act of 1873. Trees did not become established in riparian zones of the Platte River, however, until dams

were constructed, reducing river discharges and sediment loads. The reductions in discharge decreased scouring and shifting of the alluvium on the streambed, allowing extensive forest development on the floodplain since 1930. The development of woody vegetation, and subsequently a channelized river, where there was once only an open, wide, sandy, intermittent braided river, has contributed to drastic reductions in use of the area by sandhill and whooping cranes, seriously endangering these species populations (U.S. Fish and Wildlife Service 1981). In addition, the development of wooded corridors facilitated movement of eastern forest birds into the Rocky Mountains.

Sedimentation can be beneficial. As in the well-known stories of agricultural areas of the Nile River Valley relying on the annual deposition of sediments to replenish soil nutrients, all alluvial rivers transport sediment that can nourish riparian systems. Overbank flooding also allows current velocities to be reduced and particulates with associated nutrients to settle onto the floodplain floor.

Sedimentation rates vary with many factors such as the characteristics of the watershed and position within the riparian corridor. Sedimentation rates on point bars are the most rapid in comparison with other areas in stable streams. Within floodplains of Southeastern rivers, sedimentation rates are generally much lower and average less than 2 to 3 mm/yr.[1] Greatest sedimentation rates are reached within the floodplain, however, in depressions such as oxbows or pits from tipped-up tree roots.

Excessive sedimentation blocks oxygen transport to roots, a requirement for normal plant functions. The combination of stress from sedimentation and flooding can be detrimental to tree regeneration. Kennedy (1970) demonstrated that survival of 40-cm-tall water tupelo (*Nyssa aquatica*) seedlings was decreased 12 percent with only 7.5 cm of sand in shallow flooding, but survival was decreased 32 percent with deep flooding. Seedling survival was further reduced with deeper sand deposits and longer flooding periods.

Sediment accumulation rates in an area change with time, ground surface elevation relative to bank-full levels, and vegetation density. Sedimentation rates averaged 6.1 cm/yr in 50-yr-old areas up to 2.5 m above the lowest elevations where vegetation was established on point bars of the Beatton River in British Columbia. Sedimentation rates decreased to 0.8 cm/yr in 200-yr-old areas 4 m above the point bars and becoming negligible in older, higher areas where vegetation density was relatively low (Nanson and Beach 1977). Chapter 3 details further discussion of sedimentation in riparian areas.

Grazing

In addition to the physical environment determined by the hydrologic, hydraulic, and sediment characteristics of the associated streams, riparian vegetation is subjected to myriad disturbances that affect plant structure and

[1] Personal Communication, 1995, C. Hupp, U.S. Geological Survey.

composition. Grazing by natural and stocked animals is of primary importance because of the extensive damage to riparian systems caused by overgrazing. Before the extensive herds of bison were hunted to near extinction, the intense grazing pressure on prairie riparian systems was very destructive. These areas were allowed to recover, however, as the herds moved off to better forage (Costello 1981). Cattle and sheep grazing in the West brought a rapid decline of riparian vegetation in the 19th century (Bryan 1928). Extensive riparian areas throughout the country have been degraded by grazing, converting them to lower value habitats and making them the most endangered habitat type in the West (Brinson et al. 1981, Chaney, Elmore, and Platts 1990).

Riparian zones provide preferred habitat for both domestic and wild ungulates because they contain:

a. Easily accessible water.

b. More favorable terrain.

c. Hiding cover.

d. Soft soil.

e. More favorable microclimate.

f. Abundant supply of lush palatable forage (from Kovalchik and Elmore 1992).

Damage to riparian areas by grazing is initiated by consumption of and damage to the vegetation. Kovalchik and Elmore (1992) report several studies showing that although the riparian habitat covered less than 2 percent of the area and produced 20 percent of the available summer forage, cattle used 75 percent of the current year's herb growth and 30 to 50 percent of the current year's willow growth in the riparian zone. Grazing can have a stimulatory effect on plants, causing them to sprout and branch more abundantly. For example, beaked sedge (*Carex rostrata*) produced more shoots per plot in grazed versus ungrazed plots in southwestern Montana (Allen and Marlow 1992). Too much grazing, however, taxes plant energy reserves, and the plant eventually reaches a point where it cannot continue to sprout and recover. At this point, the overgrazed plant begins to loose vigor (Figure 7). Continued grazing together with additional stresses to the plant lead to loss of the vegetation.

Regeneration of riparian vegetation is limited by grazing. Recruitment and growth of willow seedlings were reduced when subjected to continued season-long, heavy to very heavy grazing in comparison with other areas that received no grazing to moderate grazing in the spring or fall (Shaw 1992). Native ungulates (elk, moose, mule deer, pronghorn, bighorn sheep, and bison) of Yellowstone National Park reduce willow seed production and establishment because they consume the flowers (Kay and Chadde 1992). In addition, grazers limit plant

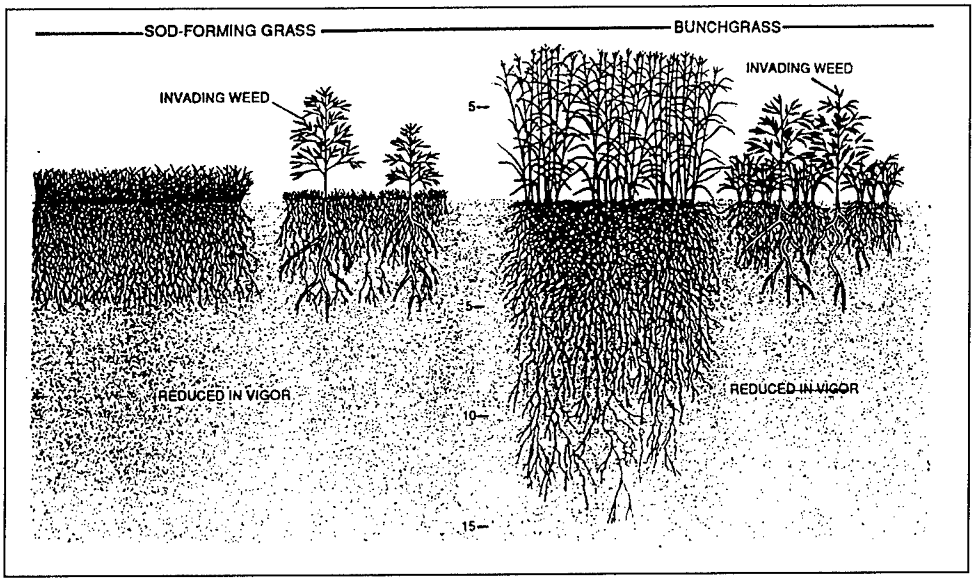

Figure 7. Overgrazing reduces root production and plant vigor of sod-forming grass and bunch-grasses and allows invading weedy species to become established (from Chaney, Elmore, and Platts 1990)

regeneration because they trample and pull out small seedlings as they feed (Kovalchik and Elmore 1992).

The bank destabilization that results from the loss of riparian vegetation leads to a predictable sequence of events that creates stressful conditions for reestablishment of the vegetation (Chapter 3). Vegetation responds to the increased erosion, lowered water tables, and increased flow rates of the degraded stream. Species that are unable to tolerate grazing or to access the lowered water tables are replaced by species that can accomplish these things. Continued grazing and flooding stress the vegetation beyond its capacity to stabilize the streambanks. Downcutting of the stream further lowers the water table and can lead to a complete turnover from riparian to lower-value upland species (Figure 8).

Riparian vegetation is subjected to a wide variety of disturbances from the adjacent stream and upland environments. In addition to those problems discussed previously, fire, debris slides, introduction of exotic species, and adjacent land uses often influence the structure and composition of riparian vegetation. Fire and debris slides are natural forces in many landscapes. Natural riparian vegetation subjected to these forces is adapted to the characteristic frequency and intensity of events in much the same manner as vegetation can be adapted to a hydrologic regime; regeneration, survival, and growth of the vegetation depend on and is timed to coincide with the predictable occurrence of the disturbance. A stable native riparian plant community is able to dominate under the series of disturbances that are characteristic of the site.

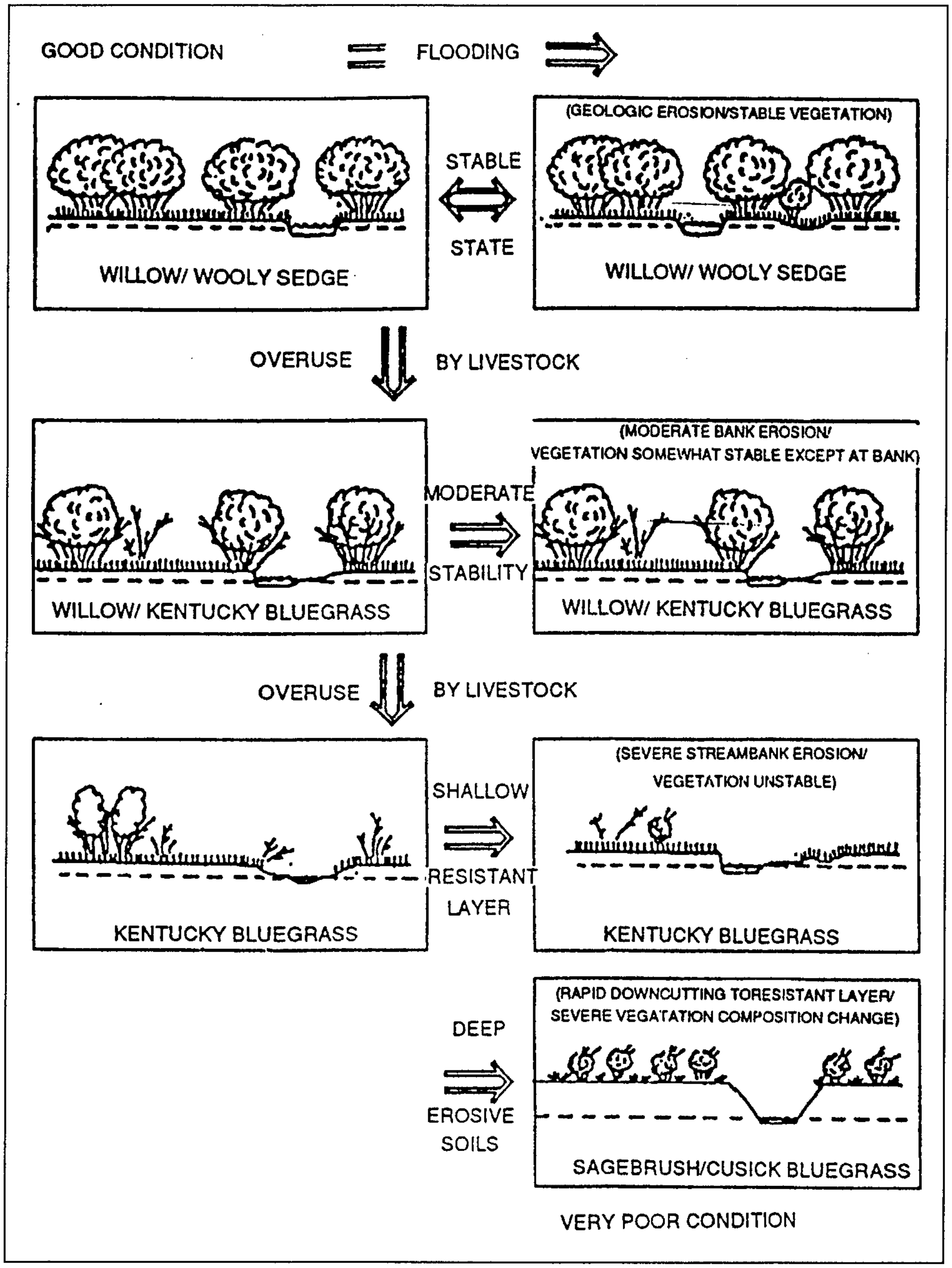

Figure 8. Deterioration of sites supporting the willow/wooly sedge (*Carex languinosa*) plant association with flooding and improper use by livestock in central Oregon (from Kovalchik and Elmore 1992)

Introduction of aggressive exotic species and changes in surrounding land uses, however, are the types of disturbances to which riparian vegetation cannot readily adapt. Exotic species are those brought to an area from elsewhere. Aggressive exotic species are often able to invade and exclude existing native vegetation because there are no natural population controls on the exotic species. Reed canary grass, for example, has spread throughout riparian zones of the northern tier of the country because of the lack of insects, fungi, or other

organisms to slow its growth. The native vegetation and associated value is usually reduced if not lost as it looses dominance. Many types of land uses encroach on riparian areas and destroy the riparian vegetation. Grazing is a primary cause of these losses, but many others exist. Forestry, agriculture, and urbanization can also be devastating to natural vegetation and its associated functions, if best management practices and sound development plans are not followed.

Functions of Riparian Ecosystems

The importance of riparian zones far exceeds their minor proportion of the landscape because of their prominent location within the landscape and the intricate linkages between terrestrial and aquatic ecosystems (Gregory et al. 1991). In addition, riparian corridors form linear connections that facilitate movement of water, sediment, nutrients, plants, and animals between upstream and downstream portions of the watershed. Landscape position, width, and continuity of the vegetated portions of these areas are critical to the hydrologic, water quality, and life support functions of riparian corridors (Table 1). In addition, it is important to recognize that riparian ecosystems have general functions that can be performed based on the hydrological, geological, and morphological conditions of the basin (Brinson et al. 1995). It should be emphasized that not all riparian ecosystems perform all functions, nor are all functions performed to the same level in all riparian ecosystems (Brinson 1993).

Riparian ecosystems and the associated functions change as streams progress and enlarge from headwaters to rivers at the base of the watershed. For example in watersheds of the Southeast, riparian corridors are narrow in the upper reaches that originate in the Piedmont region. Here the rivers are relatively steep and small; the riparian corridors are confined in the hilly terrain. Riparian vegetation is limited to narrow streamside fringes that are similar in composition to the bordering upland vegetation. Riparian corridors broaden in the rivers flowing through the relatively flat portions of the Coastal Plain. River discharge and range of stage fluctuations become larger in downstream portions of the drainage basin. Alluvial floodplains of these basins increase in extent and complexity as the rivers approach the Gulf of Mexico or Atlantic Ocean. Riparian vegetation in these areas is classified principally as bottomland hardwood swamps, which is different in species composition from the surrounding uplands. The diversity and complexity of these highly productive riparian wetlands reflect the geomorphic complexity of the alluvial floodplains.

Functions of riparian vegetation change with stream reach characteristics. For example, broad areas of dense vegetation of the bottomland hardwoods in the low gradient reach of the example cited above provide more resistance to flood flow than the narrow fringe of vegetation adjacent to the higher gradient headwaters. Wildlife value changes as well. For example, fish are able to move from the river into the bottomland hardwoods during floods to forage prior to breeding, whereas there is less opportunity to forage out of the channel in upper reaches. Similar changes in function occur among different reaches in other types of riparian systems.

3 Environmental Benefits of Vegetation

Background

The incorporation of woody vegetation within a channel designed to reduce flooding is complicated by the trade-off that exists between the environmental benefits and the hydraulic and geomorphic impacts. Compromise solutions are not always possible. But some level of riparian vegetation growth can be accommodated in most flood control projects. Table 2 lists some of the functions of vegetation in riparian ecosystems that can be considered environmental benefits.

Table 2
Functions of Vegetation in Riparian Ecosystems

Nutrient Cycling
Carbon production and export Nitrogen removal Nutrient retention
Water Quality
Particulate retention Temperature regulation Contaminant removal
Wildlife Habitat
Food Shelter Nesting habitat Travel corridors Instream substrate
Aesthetic & Recreation
Visual appeal Screens & barriers Hunting and fishing Education
Hydrologic & Hydraulic
Rainfall intercept Energy dissipation Flood attenuation Groundwater regulation
Channel Stability
Morphology maintenance Shear stress reduction Root reinforcement Soil moisture modification Buttressing

Until the benefits and impacts of vegetation within the floodplain can be quantified, conflicts between engineers and regulatory and wildlife agency staff and maintenance operators over the design and management of flood control projects will persist. This chapter focuses on the environmental benefits of vegetation, particularly shrubs and trees. Included in the discussion are the nutrient cycling, water quality, wildlife habitat, recreation, aesthetic, and channel stability benefits of vegetation.

Nutrient Cycling and Water Quality

Riparian vegetation plays a vital role in the water quality functions of riverine systems. Due to their landscape position, riparian areas intercept overland and groundwater flow from adjacent uplands as well as overbank flow from rivers. They are buffers where materials and energy from a broad areas and diffuse sources converge. Floodplains control large exchanges of sediments, organic matter, and nutrients among these ecosystems and regulate their dynamics. In addition, riparian vegetation influences other biologically important water quality parameters such as dissolved oxygen and temperature. The type and amount of vegetation within riparian areas has a profound influence on the processes that affect water quality and nutrient levels.

Much of the early concern for the consequences of channelization and other stream alterations on fish and wildlife communities focused upon the physical attributes of the aquatic system. This approach must be modified to recognize that channel alterations can not be considered separately from changes in floodplain vegetation and the resultant impacts to nutrient cycling and water quality when evaluating the environmental impacts of flood control projects.

Nutrient cycling

One of the most widely recognized functions of riparian vegetation is the contribution of carbon to downstream aquatic habitats (Brinson 1980). Carbon is a basic component of the sugars produced by plants during photosynthesis. Carbon is assimilated from the atmosphere by plants and made available as food to other organisms in the basic form of sugars. Animals eat the plants or microbes decompose the litter, transferring the energy contained in the sugars up the food chain. Litter and leachates from riparian vegetation is flushed into downstream aquatic ecosystems by floodwater and groundwater, thereby supplying energy and supporting the organisms in those areas. Measured litter fall rates for riparian forests range from 386 to 977 $g \cdot m^{-2} \cdot yr^{-1}$ (Elder and Cairns 1982). Although a large portion of this material is consumed in the floodplain, a large amount is available as a vital source of energy for downstream systems.

Transfer of particulate and most dissolved carbon from the floodplain to the river system is seasonal depending on timing and energy of flowing water. Organic carbon is exported from the riparian forest under most conditions. During low water conditions, overhanging vegetation constantly contributes small

amounts of leachates and leaf and stem matter, increasing the organic carbon concentration of river water that drained from agricultural fields. At flow levels adequate to enter the floodplain, suspended materials settle out on the forest floor, decreasing organic carbon content of the water. High flows resuspend the material, exporting significantly more organic carbon than entered the forest from upstream.

Nitrogen is also an important component of water quality, because it is one of the major nutrients required by plants and animals and is often in short supply. High N concentrations in aquatic systems results in rapid growth of algae and other organisms that use up the dissolved oxygen. Without oxygen, fish and most other organisms die. This condition is called eutrophication. Riparian vegetation removes N from water by several microbial processes called denitrification that take place in the absence of oxygen. These processes require organic matter. Riparian vegetation is very productive and produces large amounts of organic matter that serves as a substrate for microbial processing of N. Soils of riparian ecosystems have ideal conditions for denitrification: High organic matter from forest litter, seasonal waterlogging, and large inputs of N. Denitrification outputs alone were enough to remove all the N inputs from upland agricultural fields to the riparian zones in a Georgia watershed (Lowrance et al. 1984).

The flux of nutrients into, within, and out of plants is very complex, involving a number of pathways. Plant uptake is the net annual flux of nutrients into plant roots. Once taken up, nutrients may remain in the roots or be translocated upward into aboveground woody tissues and/or herbaceous tissues. Leaching, the removal of soluble nutrients from living and standing dead plants by precipitation, can return substantial amounts of nutrients to wetland surface waters. As tissues senesce, nutrients may be translocated downward, or leave the plant as litterfall or root sloughing (Johnston 1991).

Floodplain and streamside vegetation is an important source of energy for the maintenance of invertebrates and fish. Instream communities are highly dependent on leaf litter from streamside forests for maintaining metabolism and ecosystem structure. Vegetation along the water's edge dramatically increases the input of terrestrial invertebrates into the aquatic system. Vegetation roots uptake elements from the soil and bedrock, then deliver then to the stream through the process of decay. Floodplain vegetation reduces the energy of overland flows causing sediment from up-basin sources to deposit in the floodplain rather than be transported downstream in the channel. It also acts as a filter for the removal of nutrients and contaminants in stormwater runoff.

Lowrance et al. (1984) indicated that studies of a coastal plain agricultural watershed showed riparian forest ecosystems are excellent nutrient sinks and buffer the nutrient discharge from surrounding agroecosystem. Nutrient uptake and removal by soil and vegetation in the riparian forest ecosystem prevented outputs from agricultural uplands from reaching the stream channel. He noted that channelized coastal plain streams had higher nutrient concentrations than unchannelized streams, resulting, at least partially, from the loss of contact between flowing water and the riparian swamp forest. A study of riparian

peatlands of a forested watershed in Minnesota revealed that 36 to 60 percent of all annual nutrient inputs were retained in the streamside zone.

At the floodplain scale, the geomorphological and hydraulic characteristics of stream channels condition the sorting of organic material and sediment through erosion and sedimentation during floods (Gregory et al. 1991). Riparian vegetation is important in sediment retention in small drainage basins.

Well accepted is the fact that river floodplains are of primary importance in the functioning of river ecosystems. Rivers with floodplains show the relative importance of lateral versus upstream-downstream linkages of matter and energy. Thus, because of their position between terrestrial and aquatic ecosystems, floodplains control large exchanges of organic matter and nutrients between these ecosystems and regulate their dynamics. Riparian ecosystems serve as both short- and long-term nutrient filter and sink, if properly maintained, to ensure a net uptake of nutrients. Riparian vegetation plays a biologically important role in the nutrient-cycling process and should be included in designs for watershed management.

Water quality

One needs only to look at the plethora of wetlands construction projects for the treatment of wastewater and stormwater runoff to understand the role that vegetation can play in improving water quality. The same processes that foster sediment and contaminant removal in wetlands occur in vegetated riparian zones. Not only do the roots, stems, and leaves of vegetation obstruct flow and facilitate sedimentation, they also provide substantial quantities of surface area for the attachment of the microbial populations that are responsible for the removal of most contaminants. Plants also increase the amount of aerobic microbial environment in water-logged soils.

Hammer (1992) describes the importance of these processes for the Paraguay River in South America. A broad, heavily vegetated floodplain known as the Pantanal buffers the Paraguay River from many of its tributaries. In addition to untreated sewage and extremely high sediment loads from clearing and agricultural practices, these tributaries have high loads of industrial and mining pollution. For example, one iron ore mill discharges 4.8 kg of detergent per day used to wash ore stacks into the Rio Correntes, gold miners discharge 36,000 kg/yr of mercury into the Rio Couros and the Rio Aqua Branca, and eight alcohol distilleries discharge 3,600,000 ℓ/d of organic waste into rivers draining the northern plateau of Brazil. The combined impacts of these pollutants on the receiving rivers have been devastating. Amazingly, however, the concentrations of these pollutants are reduced to innocuous levels by the Pantanal before they drain into the Paraguay River. The role that riparian vegetation plays in improving the water quality of this system is but one example of its importance as a component of flood control projects.

Streamside vegetation also improves water quality and reduces streamflow nutrient loads through shading and streambank stabilization. The vegetation

canopy alters the water chemistry of throughfall and stemflow and shading can reduce eutrophication of slow-moving waters. Dense riparian vegetation not only intercepts and disperses raindrop energy, but its roots bind the soil, reducing erodibility. Mature trees that fall into the stream and create snags and log jams not only provide valuable substrate, but also alter the hydraulic condition of the channel with concurrent water-quality implications. Dead biomass from vegetation conditions the soil, aids in infiltration and percolation, and increases water storage in the floodplain.

Vegetated buffer zones can reduce the impacts of stormwater along urban floodways. Woody vegetation in conjunction with infiltration trenches controls runoff peaks, increases infiltration, controls thermal pollution, and removes organic and inorganic pollutants from the water. Studies have also emphasized that maintenance of riparian vegetation is necessary to improve water quality in agricultural watersheds. Good water quality for agricultural watersheds depends largely on nutrient uptake and removal in the riparian ecosystem. Removal of the riparian forest, often accompanied by tile drainage, tends to contribute to higher nutrient loads in streams and lower water quality.

The role of riparian vegetation strips in improving the quality of the waters is well documented. Although this influence is more pronounced in small streams than in large rivers, vegetation provides a vital role in any system. Apart from filtering the incoming suspended matter flowing from upstream, they can also prevent soil erosion from being exported to the rivers, cycle nutrients, reduce eutrophication, lower water temperatures, and provide other benefits to the chemical and biological nature of the system.

Wildlife Habitat

Introduction

All animals owe their existence to trees, grasses, weeds, farm crops, aquatics, or other forms of vegetation. Animal-eating species (including humans) are no exception to the rule, their dependence is, at most, a step or two removed. Food is one of the primary necessities of all life, and for wild animals, cover is not far behind as a vital requirement. Plants are the immediate or ultimate source of all food and most of the shelter used by wildlife.

In addition to food and cover, water and spatial arrangement determine the faunal composition of stream corridors. These four components interact in multiple ways to provide several habitat features of stream corridors, including:

a. High primary productivity and biomass.

b. Spatial and temporal diversity in food, habitat, and cover.

c. Maximized edge.

d. Seasonal migration routes and connectivity between habitat zones.

e. Critical microclimates.

Vegetation immediately adjacent to streams or along the edges of lakes and ponds is characterized by plant species and life-forms differing from those of the surrounding forest and is termed riparian. The marked contrasts between riparian and upland vegetation produces structural diversity and edge characteristics enhancing its utility for both terrestrial and aquatic wildlife. Riparian fringes consisting of shrubs and trees in both humid and arid environments support more avian species than do adjacent uplands of the same geographic region. Forest fruits, seeds and leaves, as well as insects and other foods are the base of the food webs that support 75 percent of the riverine fishery of the Amazon. Meehan, Swanson, and Sedell (1977) documented the dependence of salmonoid fisheries on the riparian forested wetlands. It has been demonstrated that the fisheries of many rivers are dependent upon floodplain inundation, and seasonality of both reproduction and feeding is closely keyed to hydrologic events in floodplains of most major rivers.

A large number of studies have documented that vegetated riparian ecosystems unquestionably provide essential habitat requirements for a large diversity of vertebrate species. Because of their long narrow shape, stream riparian areas contribute few acres to the total available habitat; however, they are highly productive so their value to wildlife is well out of proportion to their small area (Thomas, Maser, and Rodick 1980). More migratory and nesting species of birds have a higher affinity for riparian and floodplain ecosystems than they do for upland ecosystems. The highest density of birds (1,324 pairs per 40 ha) ever recorded in North America was found in riparian vegetation in Arizona.

Not only are riparian areas important to terrestrial animals, but they also control the associated lotic habitat for amphibians and fish. Canopies provide shade, root systems stabilize banks, and plant detritus and insects provide nutrients for stream organisms (Meehan, Swanson and Sedell 1977). Riparian areas create an oasis effect in dry lands, and, because of their cooler microclimate and free water, they are major resting places for many migrating birds. In addition, tall trees along a stream or watercourse at times create a fluelike condition causing an updraft which brings in air underneath the vegetation and over the water.

Riparian vegetation provides a natural travel corridor for many species such as dove, deer, turkey, and coyote. This phenomenon is particularly important in arid climates, where riparian corridors often provide the only suitable cover for animal movement. In the eastern United States, the riparian zone is not as distinct as it is in the west, because higher rainfall results in more vegetation perpendicular to the aquatic region of the riparian zones. Thus, the increased moisture and deeper soils integrate the vegetation types lessening the distinction between where riparian starts and ends. Despite this, most animals show a preference for the vegetated regions nearest the stream corridor.

This section presents a brief overview of the benefits of vegetation to wildlife. Although, from an ecosystem perspective, this subject could cover everything

from energy processing to the hydrologic cycle to animal behavioral science, the scope of this discussion is limited to the value of vegetation in providing food and shelter.

Food

The aggregate of data from the past 100 years of research on the foods of American wildlife provides only a fragmentary indication of the foods most utilized by wildlife. The gaps in information are often as conspicuous as the solid framework of knowledge. Even for wildlife species that have been studied intensively, food preference, food requirements, and food availability are only partly known because of an incomplete accounting of the items actually eaten.

The lower plants, from bacteria and algae up through the mosses and ferns, are of only limited direct value to wildlife. The highest botanical group, the seed plants, is by far the most important to wildlife. This large group, with its two main subdivisions, the conifers and the broad-leaved flowering plants, includes about 25,000 species in the United States. In it are all the common trees, shrubs, vines, weeds, and marsh plants. The somewhat less natural plant communities of farm croplands also have their associated wildlife.

Although nearly all plant types are important components of the riparian ecosystem, the focus of this research effort is on the woody species and, in particular, shrubs. More than 1,000 naturally occurring species of shrubs, semishrubs, and woody vines grow in the United States. Probably every shrub species provides food or cover for some animal species.

The planting and production of shrubs was emphasized in the past, particularly in the West, because of their importance in maintaining big game populations. More recent ecological thinking has encouraged their cultivation for a variety of other life-forms as well. Many shrubs that are browse food plants for deer and elk also provide seeds and fruits for birds and small mammals and, in many cases, also provide cover for the same groups of species.

Nearly all parts of plants can be and are consumed by one animal species or another. Fruits, seeds, leaves, twigs, bark, stems, and roots all furnish food to different kinds of animals. Fruits, rich in carbohydrates and vitamins, are especially important, relished foods. Fleshy fruits are mainly products of woody plants like shrubs and are generally available in summer and fall. Some persistent ones like holly, grape, snowberry, mountain-ash, manzanita, and persimmon are also available to wildlife in winter.

Botanically, nuts are fruits with a dry, hard exterior. Animals use these hard-shelled fruits extensively, probably because they are unusually rich in fats and proteins and are available over long periods. Dry fruits from woody plants most sought by wildlife include acorns, pecans, beechnuts, and cultivated walnuts. Like nuts, seeds are concentrated food parcels and are eagerly sought. They constitute the major food of many birds and small mammals, making up practically the entire diet of some common species. New crops of seeds usually

mature in summer or fall, but part of the crop may remain available for use later in the season, either on the plants of on the ground.

Browsing and grazing mammals, some rodents, and a few gamebirds make the vegetative parts of plants a major part of their diet. Almost any kind of foliage is taken by hoofed browsers, though eating of tough leaves (such as conifer needles) may sometimes represent necessity rather than choice. All aerial parts of small herbaceous plants are eaten, though the flowering or seed-producing parts are often favored. Browsing on woody plants usually includes the eating of leaves and twigs together, except in winter. Besides twigs taken by browsers, inner bark or wood is important, but only for a few mammals: beaver, porcupine, rabbits and certain mice. Other special uses of plants parts include nectar from flowers used by hummingbirds and plant galls taken by the California bushtit and various other birds as well as by the gray squirrel.

A prime factor in the use of any kind of food by wildlife is its availability. Unfortunately, there is no such thing as a constantly available food supply for wild creatures, and so birds and mammals live under seasonal threat of starvation. The availability of plant food is limited not only by the ranges and habitats of the plant concerned but also by seasonal factors. In the spring, swollen buds, tree flowers, trees, tender vegetation, and a few rapidly maturing dry fruits (such as elms and silver maples) become available. Later in the summer many more kinds of seeds mature and fleshy fruits ripen. Fall is the season of plenty when plant products abound and when most animals become fat. Seeds, nuts and fleshy fruits can be obtained with little trouble by animals which eat them.

Winter, especially late winter, is a time of hardship for most wildlife. It is a critical period for food supply. In the temperate regions, especially the north temperate, the whole character of the environment changes. The available supply of both insect and plant food decreases markedly as the weather grows colder and the first frost arrives. The insect supply suffers most, and wildlife species turn more and more to plant foods. Both plant and insect eaters search more intensely over wider areas to find food.

There are many parallels between the nutrition of wildlife and that of humans. We recognize that our own diet must do three things: furnish heat and energy, promote growth and reproductions, and protect against deficiency diseases. So must the diet of wildlife. Wild animals, like ourselves, may suffer from vitamin and mineral deficiencies. Normally, the diet of birds and mammals is balanced in terms of their needs, and the foods preferred and selected are generally those suited to the animal's welfare.

The nutritional value of plant food varies in different parts of the same plant and also from plant to plant. Leaves are primarily a carbohydrate food and tend to be richer in vitamin A and calcium than other parts of the plant. They have, however, a high moisture content and so are of relatively low nutritional value. Buds and flowers are similar to leaves nutritionally, though buds contain less water. Roots, rootstocks, bulbs, and corms are packed with carbohydrates and some proteins. In carbohydrate content, it is at least the equivalent of leaves.

Fleshy fruits are rich in carbohydrates and vitamins. Seeds and nuts are the most concentrated of plant foods. They are the richest sources of fats and proteins and also contain minerals and most of the B complex vitamins. As wildlife foods, they have no equal. Add to this the fact that spoilage is low and some seeds and nuts are available throughout the winter, and you can see why they rank as high as they do. Despite the high value of seeds and nuts, plant foods have their nutritional limitations. As compared to animal products, they are generally low in protein and even lower in fats. Therefore, many animals, particularly birds, augment their vegetation diet with insects.

Because of the great variation in the nutritive content of plants, wildlife biologists are still seeking a single index of plant nutritional value. Animals need vitamins, fats, proteins, minerals, and carbohydrates. But protein seems to be the most likely indicator of plant nutritional quality. Some of the factors affecting the crude protein content of plants are soil moisture, canopy closure, soil nutrients, grazing intensity, and burning. While protein is a good indicator of plant quality, the complete nutritive value of a plant must be compared with the requirements of a species.

Cover

Food and shelter are primary necessities of both humans and wildlife. For wildlife, the two are more intimately connected. Frequently, the same plants that serve as food also provide cover. Cover is the physical habitat or landscape feature that provides an animal protection from hazards and predators (Patton 1992). Cover is generally defined by the function it serves, i.e., protective, escape, feeding, breeding/nesting, resting, and roosting cover. Vegetation is the primary component of cover in most wildlife habitats and usually serves more than one function. For example, woody vegetation provides nesting, denning, resting, and roosting cover for a wide variety of birds and mammals, as well as breeding and protective cover for amphibians and reptiles; herbaceous vegetation may be used for nesting and protective cover by terrestrial ground- and marsh-dwellers. An animal frequently uses a particular type or structural level of vegetation for more than one life activity; e.g., white-tailed deer may forage, hide their fawns, and rest in the dense cover of a bottomland hardwood forest.

The cover requirements of individual species are as variable as species' food requirements. Cover is furnished by vegetative structure (trees, shrubs, grasses, and forbs), as well as by stages within life-form (seedling, sapling, etc.), topographic features (aspect, hills, valleys, soil, etc.), and water. Protective cover may be used for hiding, escape through vegetative corridors in open or semi-open habitats, or insulation against the weather (thermal cover). Herbaceous vegetation in edges around fields or along ditch banks in agricultural lands serves as escape cover for amphibians, reptiles, ground-dwelling birds, and small mammals. Forests provide not only escape cover but also thermal cover for mammals, amphibians, and fish.

Although cover provides protection, there are special types of cover associated with specific functions for each wildlife species. Trees, for example,

can provide thermal cover for animal life; coniferous trees shelter wildlife from winter elements in northern climates, while deciduous trees provide shade relief and thermal regulation necessary for the survival of some animals in hot summer climates. Shrubs are particularly important in providing cover to birds and small mammals.

Single live trees provide the physical structure needed for a nest by a squirrel or a hawk, for overnight roosting by wild turkeys, or for perching and resting by doves and pigeons. When single trees accumulate to make a small group and can be identified as a stand, then additional protection is provided to many forms of wildlife. In their early developmental stage, sprouts, limbs, or twigs of trees are food for browsing animals such as deer and elk. The importance of live trees in providing wildlife food and cover cannot be over-emphasized.

In addition to general types of cover, for some species there is a subset that can be identified as shelter. Shelter is associated with the rearing of young, such as in a nest. For example, the Albert squirrel builds a nest in a single ponderosa pine where young are born. This nest occurs in a tree surrounded by a group of trees. The tree group and individual nest tree provide cover from weather and predators, but the nest (shelter) provides additional protection for the young. Not all species have specific shelter requirements but some types of shelter used are rock crevices, tree cavities, hollow logs, ground dens, and burrows. The quantity of cover necessary to support wildlife varies greatly with the particular species, climate and topography as well as the condition of the ecosystem. Table 3 provides data indicating the minimum riparian buffer strip widths required to support breeding bird populations in Iowa.

Table 3
Minimum Riparian Buffer Strip Widths Required to Support Breeding Bird Populations in Iowa

Species	Buffer Width, m
Cardinal	11
Blue jay	15
Black-capped chickadee	15
Downy woodpecker	15
White-breasted nuthatch	17
Eastern wood pewee	20
Great crested flycatcher	35
Brown thrasher	40
Hairy woodpecker	40
Red-eyed vireo	40
Red-bellied woodpecker	90
Warbling vireo	90
Tufted titmouse	100
Wood thrush	135
Blue-gray gnatcatcher	150
Ovenbird	175
Scarlet tanager	200
American redstart	200
Rufous-sided towhee	200

Dead trees, snags, hollow trees, decaying logs, and stumps are used as hunting perches for raptors as den trees for raccoons, squirrels, and bears; as feeding sites for woodpeckers; and as nests for cavity nesting birds. On occasion, rabbits use rotted tree root canals for tunnels and dens, as do snakes, lizards, and small rodents. The cavity nesting birds are a particularly important class of forest birds because the majority of them are insectivorous and help control endemic forest insects that damage valuable timber trees.

When discussing cover and shelter requirements of specific species, caution is urged in not transferring the requirements across geographical boundaries or vegetation types unless studies or experience have shown that the requirements are similar in the hierarchical levels being compared.

Spatial arrangement

Wildlife habitat is not just trees, shrubs, grass, weeds, or even crops. It is a complex mixture of plant communities or cover types. All play a role in meeting the needs of a particular species, and all must be present within the species normal range for that species to be present. Diversity is the key to good land management, and a stable vegetated riparian ecosystem should have diverse plants of all ages to support a large variety of wildlife and recreation uses as well as provide water quality and stabilization benefits. In other words, uniform stands of one or two plant species should be discouraged.

Riparian sites usually are extremely heterogeneous, containing different plant communities, topographic conditions, parent materials, and soils within a short distance. The arrangement or interspersion of cover types or plant communities is important to wildlife. Two units of land can have the same size and quantities of cover types, and be managed comparably, but support different wildlife populations, depending on how the cover types are interspersed or arranged.

Wildlife biologists refer to junctions between communities as "edges" and to the phenomenon of increased numbers of a species at these junctions as "the edge effect." Hunters may not call those areas anything, but they gravitate to them because they know from experience they can expect to see more game animals and birds there. The land-water interface along a flood control channel provides one edge type. If a project includes low- or high-flow channels, compound channels or levees, these also form a type of edge. Likewise, variations in vegetation communities within a project can form edges that are important to wildlife.

Numerous studies have demonstrated that complex habitats support more species than structurally simple habitats because more resource dimensions are available, and these can be exploited in more ways (Pianka 1967, Karr and Roth 1971, Rosenzweig 1973, Cody 1974, Cody 1981). The unique arrangement of riparian vegetation and other habitat features allows a greater complexity of habitat development.

Plant associations have diffuse edges. Riparian systems, at the interface between aquatic and terrestrial habitats, demonstrate the ecological principal of edge effect; i.e., the diversity and abundance of species tend to be greatest at the ecotone, or "edge" between two distinct ecotypes (Odum 1978). The close proximity of diverse structural features in a riparian ecosystem results in extensive edge and structurally heterogeneous wildlife habitats (Brinson et al. 1981). Both species density and diversity tend to be higher at the land-water ecotone than in adjacent uplands, especially in arid climates. Edges and their ecotones are usually richer in wildlife than adjoining areas because they harbor species from multiple ecotypes (Thomas, Maser, and Rodiek 1980). The interface between stream and woody plant communities contains many species (e.g., river otter, alligator, yellow-crowned night heron) that occur almost entirely in this zone (Brinson et al. 1981). Riparian-upland ecotones contain many upland and edge species (e.g., cottontail rabbit, canebrake rattlesnake, summer tanager) where woody riparian communities adjoin relatively open ecotypes such as rangeland, grassland, or farmland (Thomas, Maser, and Rodiek 1980).

The linear nature of riparian ecosystems along rivers creates distinct corridors, or pathways, for birds and mammals to use as migration and dispersal routes and as protective forested connectors between habitats (Brinson et al. 1981). Birds, bats, deer, elk, and small mammals use these corridors, which provide the woody vegetation needed for food and cover by migrating and terrestrial species (Blair 1939, Rappole and Warner 1976, Stevens et al. 1977, Wauer 1977, Wilson and Carothers 1979). The value of riparian corridors for animal movement is accentuated in arid regions (Wauer 1977) and in landscapes where upland habitats have been converted to other uses such as agriculture.

The size (width and/or area) of a plant community has a direct relation to its ecological values, but standard dimensions have not been determined for the size of riparian stands needed to support maximum wildlife populations (Brinson et al. 1981). Even very narrow strips of riparian vegetation are important to instream communities and wildlife that inhabit shorelines; species such as the belted kingfisher and mink often establish territories in narrow riparian woodlands (Curtis and Ripley 1975). However, narrow woodland strips are unsuitable for animals requiring large tracts of forest, such as the black bear (Landers et al. 1979), osprey (Swenson 1979), and great blue heron (Scott 1980).

The area of riparian vegetation most heavily used by terrestrial wildlife is that within 200 m of a stream (Brinson et al. 1981). Many mammals, reptiles, and amphibians concentrate their activities within 60 m of water (Organ 1961, Tilley 1973, Krzysik 1979). Dickson and Huntley (1985) found that uncut hardwood stringers through young pine stands in East Texas contained resident populations of gray squirrels only if they were more than 50 m wide. Terrestrial small mammals (Dickson and Williamson 1988) and herpetofauna (Rudolph and Dickson 1990) are more abundant in narrow streamside (0 to 25 m) zones characterized by intact overstory and midstory, sparse shrub and herbaceous vegetation, and abundant leaf litter than in wider zones without this vegetation structure.

Although some avian species will move as much as 4 km from nesting to foraging areas (from sources compiled by Brinson et al. 1981), a 200-m-wide strip of riparian vegetation will accommodate the breeding territories of most songbirds (Stauffer and Best 1980). Minimum corridor widths for 20 species of birds in Iowa ranged from 10 to 200 m, with scarlet tanagers, American redstarts, and rufous-sided towhees requiring the widest corridors. Although Stauffer and Best (1980) found yellow-billed cuckoos in fairly narrow corridors, Gaines (1974) reported that cuckoos in California required riparian strips at least 100 m wide and 300 m long.

Keller, Robbins, and Hatfield (1993) counted birds in 117 wooded riparian corridors in the largely agricultural landscape of the Delmarva Peninsula in Maryland and Delaware. They found that the number of year-round resident bird species did not vary with riparian zone width, but that the number of neotropical migrant species increased with corridor width. Short-distance migrants declined slightly with increasing width. Corridors <100 m wide were dominated by short-distance migrants, whereas those >100 m wide supported more neotropical migrants, including several area-sensitive species such as Acadian flycatchers, wood thrushes, and Kentucky warblers.

Although they did not report corridor widths, Gutzwiller and Anderson (1987) determined critical sizes of riparian woodland fragments in Wyoming for various species. These included about 2 ha for red-headed woodpeckers, 6.8 ha for black-capped chickadees, and 15 ha for tree swallows. In desert areas of California, even fairly small (0.2 to 9.8 ha) riparian oases attracted large numbers (41 to 82 species) of breeding and migrating birds; however, only sites larger than 10 ha supported more than 100 species of birds (England, Foreman, and Laudenslayer 1984).

Vegetation species providing food and cover

The acquisition, handling, layout, and maintenance of vegetation species necessary to provide the diversity described above for a flood control project can be daunting. In some cases it may be possible to avoid this altogether. If a remnant composition of desirable plants exists, natural restoration may be most practicable. Artificial revegetation normally should not be employed unless satisfactory recovery cannot be achieved by natural means within an acceptable period. Most riparian shrubs and trees are capable of resprouting and can recover from extensive use. Nonsprouting species are slower to recover and may reappear erratically. A satisfactory seed source may exist, and it may be necessary only to provide temporary cover until seedbed conditions on disturbed sites are conducive to seedling establishment. Although protected sites may recover slowly at first, once soil surfaces stabilize new plants often appear rapidly.

In cases where the preproject plant composition was inadequate or the time for natural recovery is unacceptable, it will be necessary to select plant species and develop a landscape design. Plants are not all equal in terms of their benefits to wildlife. This is not to downplay the importance of every species' role in a functioning ecosystem. However, if it is necessary to establish vegetation within a

floodplain, it stands to reason that the mix of species selected should include some that provide particularly high wildlife benefit. The following paragraphs provide insight into species that should be considered based upon their wildlife value.

In restoration programs, dual-purpose plants have a special place. Plants that offer both shelter and food have more than a double advantage. This ideal combination of food and shelter is provided by many plants in varying degrees of adequacy. Holly and some pines are good dual-purpose trees for many birds. Bobwhite quail have found a recently introduced perennial, shrub lespedeza (*Lespedeza bicolor*), an excellent dual-purpose plant. The heavy crop of seeds of this legume is relished by the bobwhites, and the dense growth provides some cover in winter as well as during the growing season. Wildrice and bulrushes are fine food and shelter plants for waterfowl. Sorghum, sunflower, millet, cowpeas, and soybeans that are sometimes planted for gamebirds furnish cover as well as food; but for maximum value for quail, pheasant, and turkey, the food patches are often placed alongside hedgerows or against woodlots so that the birds have accessory cover available when feeding. In the last decade, multiflora rose has come into extensive use as a dual-purpose plant. It furnishes cover and food and also serves as a living fence.

Another type of dual-purpose plant is set out primarily to control soil erosion and to get denuded land back under plant cover. These plants are selected because of their tolerance to unfavorable conditions, because of their rapid growth, or because of root systems that are effective in anchoring soil. Secondarily, they provide food and cover for wildlife. Grasses, lespedezas, and other legumes are planted to hold the soil in open fields. Conservation studies have made it clear that worthless eroded land planted with dual-purpose soil-conservation and wildlife plants may begin to yield a wildlife harvest in just a few years.

Hedgerows are valuable since they serve the dual purpose of providing cover and food for wildlife. A hedgerow forms naturally when native plants are allowed to develop along a fence of field border. This strip is, in effect, an extension of the forest border - a natural wildlife path into the cultivated areas. It provides food as well as escape and nesting cover. The proximity of nesting birds in hedgerows may provide some measure of protection against insect depredations to crops. Many of the hedgerow plants that establish themselves naturally in the East are valuable food producers for wildlife (poison-ivy, wild cherry, persimmon, blackgum, dogwood, honeysuckle, etc.). Farther west, hedgerows are planted for the primary purpose of establishing windbreaks. Typical wildlife of hedgerows includes many kinds of songbirds, several upland gamebirds, and various mammals, such as rabbits, opossums, raccoons, foxes, and small rodents.

Another special group of plants useful to wildlife because of their combined cover and food potentialities are the aquatic and moist-soil plants that attract ducks and geese to our swamps, marshes, and waterways. Like hedgerows, many of these plants grow naturally and, unless disturbed by drainage, changes in water level, or harmful burning, will maintain permanent cover and a good food supply for marsh wildlife. Plants like sago pondweed, other pondweeds, duckweeds, and wildcherry are excellent waterfowl foods that also furnish cover for fish. The

bulrushes, wildrice, wildmillet, spikerush, and similar erect, densely growing plants provide nesting cover as well as a fall and winter supply of seeds. The leaves, stems, tubers, and seeds of aquatic plants are consumed by waterfowl, muskrats, beaver, moose, and occasionally by deer. Water plants of outstanding food value are the pondweeds, wildcelery, wildrice, eelgrass, and naiads.

Although not normally a component of flood control projects, agricultural crops in the project vicinity or incorporates within the seed mix can substantially improve the value of the site to wildlife. Agricultural crops that have the greatest appeal to wildlife include corn, wheat, barley, oats, sorghum, rice, alfalfa, soybeans, cowpeas, and various cultivated fruits. Some major crops such as cotton, tobacco, sugar beets, and potatoes benefit wildlife very little, if at all.

Weeds are generally unwelcome intruders, but because of their abundant seeds, they are more valuable as wildlife foods than most of our more attractive, showy flowered plants. The number of seeds produced on a single annual weed may be enormous. Pigweeds can bear as many as 100,000 seeds per plant. The most important weed seeds used as wildlife foods are from common, widespread species; pigweed, ragweed, crabgrass, bristlegrass, goosefoot, doveweeds, filaree, smartweeds, knotweeds, redmaids, tarweeds, dock, and deervetch. The seeds (grains) of wheat, corn, barley, and oats are, of course, especially attractive to wildlife and are used whenever available. Pine seeds and seeds of other conifers also rank high in food use.

Herbaceous plants include the many species of grasses such as wheatgrasses, bluegrasses, and bromes, and the low, wide-leaved flowering plants such as buttercups, cinquefoils, and clovers, often referred to as forbs. Grasses, grass-like, and herbaceous plants are important sources of wildlife food and provide cover for a range of animals from small mammals - for example, chipmunks, mice, and ground squirrels - to large grazing animals, including elk, deer, and pronghorn.

Although each of the classes of vegetation discussed above are important to wildlife and should be incorporated into revegetation projects, the focus of this study is on shrubs and trees. Trees and shrubs in particular are extremely important in meeting the food and cover requirements of wildlife. Although there are about 650 native trees, of the 100 trees introduced and 1,000 shrub species found in the United States, only about 100 or so have the combined attributes of floodplain adaptation and high value to wildlife.

Among shrubs, the widely distributed rose family (*Rosaceae*) provides a large proportion of the more important wild fleshy fruits including blackberry, strawberry, raspberry, cherry, rose, serviceberry, hawthorn, apple, and mountain-ash. Additional fleshy fruits of wildlife importance are grape, holly, blueberry, persimmon, sassafras, and blackgum. These are valuable to many kinds of birds and some mammals such as the raccoon, deer, bear, fox, squirrel, skunk, and opossum.

Approximately 35 genera make up the groups of tree species across North America that are most commonly used by wildlife. The list includes a mix of conifers and hardwoods. Conifers most often cited for their food and cover during

severe winter conditions include the pines, hemlocks, cedars, and junipers. Hardwoods, particularly those that are mast-producing, provide shelter but are perhaps more important for their food value. Hard-mast producers of high value include oaks, hickories, beeches, walnuts, and hazelnuts. Soft-mast producers include cherries, dogwoods, hawthorns, and ashes.

Various researchers, botanists, and wildlife conservationists have developed lists of species considered to have high value to wildlife. Tables 4 and 5 summarize the lists for shrubs and trees, respectively, from various sources.

Table 4
Flood-Tolerant Shrub Species

Genus Species Name	Common Name	Location
Alnus serrulata	Common Alder/ Hazel Alder	N, S, E
Artemisia tridentata tridentata	Basin Big Sagebrush	W, NW
Atriplex lentiformis	Quail Bush	SW, W
Baccharis glutinosa	Water Wally/Seep Willow	W
Baccharis viminea	Mule Fat	W
Betula papyrifera	Paper Birch	NE, C, W
Cephalanthus occidentalis	Buttonbush	Nationwide
Chilopsis linearis	Desert Willow	W, SW
Cornus amomum	Silky Dogwood	N,E,SE
Cornus stolonifera	Red Osier Dogwood	N, NE, NW
Franseria dumosa	White Bursage	W, SW
Ilex cassine	Dahoon	S, SE
Ilex decidua	Possum Haw	NE, C, E
Itea vierginica	Virginia Willow	NE, E, SE
Ligustrum sinense	Chinese Privet	S,SE
Lonicera oblongifolia	Swamp Honeysuckle	E
Lycium halimifolium	Box Thorn/Wolfberry	N, W, SW
Myrica gale	Sweet Gale	NE
Nyssa sylvatica	Black Tupelo	C, E, SE
Phragmites communis berlandieri	Reed	NE,E, C, SW
Rhododendron viscosum	Swamp Azalea	E, SE
Rhus aromatica	Fragrant Sumac	E,SE,C,SW
Ribes triste	Swamp Red Currant	E
Rosa palustris	Swamp Rose	E, SE
Rubus hispidus	Swamp Dewberry	E, SE
Salix bebbiana	Bebb Willow	C
Salix cotteti	Bankers Willow	Nationwide
Salix interior	Sandbar Willow	N,NE,E,C
Sambucus canadensis	American Elderberry	NE,E,SE,SW
Sambucus cerulea	Blueberry Elderberry	W
Sambucus mexicana	Valley Elderberry	N,SW
Sambucus racemosa	Red Elderberry	N,NW
Symphoricarpos albus	Snowberry	N,NE,E,NW
Vaccinium oxycoccus	Small Cranberry	Nationwide
Viburnum alnifolium	Hobblebush Viburnum	E,NE
Viburnum dentatum	Arrowwood Viburnum	E
Vitis californica	Wild Grape	W

Table 5
Flood-Tolerant Tree Species

Genus Species Name	Common Name	Location
Acer negundo	Box Elder	NE, SE, SW
Acer rubrum	Red Maple	N,S,E,C
Acer saccharum	Sugar Maple	E, SE
Alnus rubra	Red Alder	NW
Betula nigra	River Birch	Nationwide
Celtis laevigata	Sugarberry	SE, E, C
Chamaecyparis thyoides	Atlantic White Cedar	S,SE,E,NE
Cornus florida	Flowering Dogwood	NE, E, SE
Diospyros virginiana	Persimmon	S
Fraxinus pennsylvanica	Green Ash	Nationwide
Ilex opaca	American Holly	Nationwide
Magnolia virginiana	Sweetbay Magnolia	SE
Nyssa aquatica	Water Tupelo	SE
Platanus occidentalis	American Sycamore	SE, E, NE
Platanus racemosa	California Sycamore	SW, W
Populus deltoides	Eastern Cottonwood	Nationwide
Populus fremontii	Fremont Cottonwood	SW,N,C,W
Quercus laurifolia	Laurel Oak	E, SE, SW
Quercus lyrata	Overcup Oak	SE, C, E
Quercus michauxii	Swamp Chestnut Oak	SE, E, C
Quercus nigra	Water Oak	SE, E, C
Quercus phellos	Willow Oak	NE,E,S
Quercus rubra	Red Oak	E, SE
Quercus shumardii	Shumard Oak	SE, E, C
Sabal palmetto	Cabbage Palmetto	E, SE
Salix amygdaloides	Peachleaf Willow	N,S,C
Salix discolor	Pussy Willow	N,NE,W, SE
Salix nigra	Black Willow	NE,E,SE,SW
Salix purpurea	Streamco/ Purple Willow	Nationwide
Taxodium distichum	Bald Cypress	SE, E, NE
Ulmus americana	American Elm	NE, E, SE

Importance of Riparian Vegetation to Aquatic Fauna

Riparian vegetation is an important component of aquatic faunal habitat. Platts (1983) and Moring, Garman, and Mullen (1985) reviewed the role of streamside vegetation from the perspective of fisheries habitat and described five important riparian functions: (a) provision of fish cover; (b) provision of streambank stability; (c) regulation of stream temperatures; (d) input of nutrients to the system by allochthonous material; and (e) direct input of invertebrates as fish food.

Cover

Cover for fishes refers to instream areas that provide quiet resting places and protection from predation (Wesche, Goertler, and Frye 1987). It may be the most fragile and important element affecting a fishery (Platts 1983). The importance of cover to fish is well documented by the many studies that have found salmonid

abundance declining as stream cover was reduced (Boussu 1954) and increasing as cover was added (Hunt 1976, Hanson 1977, Binns 1979).

Streamside vegetation provides cover by creating quiet, shaded resting areas where it overhangs the water surface (Figure 9) and by contributing material for the formation of debris and log dams (Platts 1983). Wood boles (>10 cm in diameter) from the riparian forest enter streams of all sizes (Naiman, Decamps, and Pollock 1993). Large pieces of debris and log jams create pools and protective cover for fishes, especially salmonids in small mountain streams (Meehan, Swanson, and Sedell 1977).

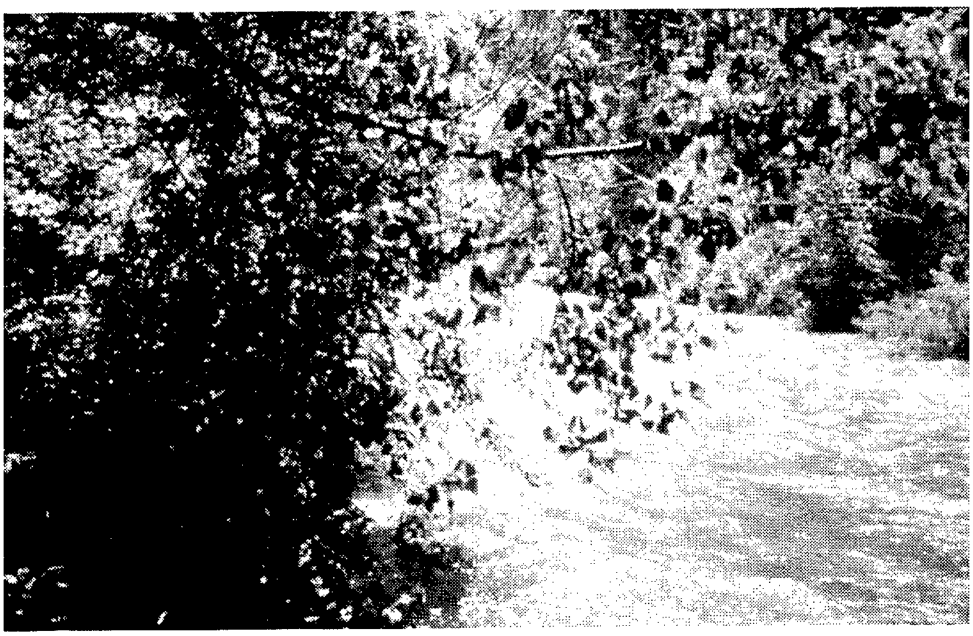

Figure 9. Overhanging riparian vegetation cools aquatic habitats

Results of a study to evaluate the relative importance of cover parameters to trout populations in small streams indicated that overhead bank cover, provided primarily by riparian vegetation, is the parameter that explains the greatest amount of variation in trout population size (Wesche, Goertler, and Frye 1987). The amount of overhead bank cover available in small streams predominated by brown trout (Salmo trutta) exerts the strongest influence on trout carrying capacity, and the riparian system is the dominant factor controlling this cover type. The findings of Wesche, Goertler, and Frye (1987) quantitatively verify the conclusion of Platts (1983) that banks bordering small streams (order <6) provide the habitat edges or niches needed to maintain high fish populations.

Streambank and channel stability

Riparian vegetation plays an important role in building and maintaining productive streams (Platts 1983). Stems and low-hanging canopy retard movement of sediment, water, and floated organic debris during floods (Swanson,

Fredrickson, and McCorison 1982). Riparian trees provide streambank stability because of their large size and massive root systems, and brush builds stability through its root systems and litter fall (Platts 1983). Grasses form the vegetative mats and sod banks that reduce surface erosion and mass wasting of streambanks.

Trees are especially important in maintaining channel stability (Platts 1983). As they mature and fall into or across streams, trees not only cause high quality pools and riffles to form but their large mass helps to control the grade and stability of the channel. If it were not for the constant entry of large trees falling into the stream, the channel in many aquatic types would degrade and soon flow on bedrock. This would result in insufficient spawning gravel and few high quality rearing pools for salmonid fishes.

Fish are often adapted to the habitat interface between the streambank and water because stable, well-vegetated streambanks provide cover, control water velocities and temperatures, and supply terrestrial foods (Platts 1983). The condition of the streambank often governs the water depths and velocities the fish must live in. Therefore, streamside vegetation needs high vigor, density, and species diversity because each of the vegetative types plays an important role in forming and protecting the aquatic habitat.

Stream temperature control

Riparian vegetation, chiefly tree canopy and stems, above the stream channel provides shade that controls temperature and in-stream primary production (Swanson, Fredrickson, and McCorison 1982). Temperature changes can affect the metabolic rates of fishes, change the dissolved oxygen content in the water, and influence hatching success (Platts 1983).

Shade reduces water temperatures in summer and protects against heat loss in winter (Platts 1983). Unusually high stream temperatures can lead to disease outbreaks, cessation of feeding, stopping of migrations, and inhibition of fish growth. Temperatures above 68 °F (20 °C) have completely stopped fish migration, while temps above 77 °F (25 °C) are often lethal to salmon and trout (Reiser and Bjornn 1979). Riparian vegetation not only intercepts and reduces the intensity of solar radiation but also provides shade for cover, especially along stream margins (Platts 1983). This type of cover can be critical to good fish survival because shaded streamside areas are a preferred habitat of juvenile salmonids.

Streamside vegetation also protects against extremely cold temperatures. Streams with little or no vegetative canopy are susceptible to the formation of anchor ice, which can form on cold clear nights when the channel radiates heat directly into the atmosphere (Platts 1983). Heavy formations of anchor ice can produce a complete fish kill or restrict the oxygen supplied to fish eggs in the gravel.

Certain types of vegetation are needed to control stream temperatures (Platts 1983). Grasses can provide overhanging cover but their shortness makes them

ineffective in intercepting the sun's rays, except in very small streams (orders 1 and 2). The height of the vegetation is proportional to the width of the stream. In large streams (order 6 or larger), trees must border the stream to provide effective shading. In small to medium streams (orders 3 to 5) brush is sufficient, but grasses and forbs have little effect.

Nutrient input

Riparian forests add large amounts of leaves, cones, wood, and dissolved nutrients to low- and midorder streams (Gregory et al. 1991). These organic inputs originate as particles that fall directly from the forest into the stream channel or move downslope along the forest floor by erosion and as dissolved materials in subsurface water.

The riparian forest helps regulate stream productivity through the amounts and qualities of material directly contributed to the stream. Small streams annually receive 300 to 600 g of carbon per square meter, with the rate per unit area decreasing as channel width increases (Conners and Naiman 1984). In deciduous riparian forests, >80 percent of these organic inputs may be leaves that enter the stream over a 6- to 8-week period in autumn, whereas in coniferous riparian forests, 40 to 50 percent of the material may be cones or wood.

Subsurface water moving from the uplands to the stream carries large quantities of dissolved organic matter and nutrients essential for stream function (Naiman, Decamps, and Pollock 1993). Riparian forests chemically alter these materials as the subsurface water flows past their root systems. Riparian forests take up nutrients for growth, promote denitrification, and modify the chemical composition of carbon and phosphorus (Pinay et al. 1990). The presence of riparian forests significantly regulates the amount of nitrogen and phosphorus reaching streams from upland areas (Karr and Schlosser 1978; Schlosser and Karr 1981).

Macroinvertebrates

Riparian vegetation provides substrate for the production of macroinvertebrates, a major source of food for fishes. Macroinvertebrates are those invertebrates that are large enough to be seen without magnification; the main taxonomic groups occurring in freshwater environments are annelids, crustaceans, flatworms, mollusks, and insects (usually predominant) (Platts 1983).

Macroinvertebrates are important intermediaries in the utilization of plant material (e.g., algae, vascular hydrophytes, leaves, and wood) and the recycling of nutrients in aquatic environments (Platts 1983). Riparian forests affect food quality and quantity for macroinvertebrates both directly and indirectly. The input of particulate matter (detritus) can be used directly for food by macroinvertebrates, while the structure and productivity of the microbial food web is influenced indirectly through stream shading and modification of levels of dissolved organic carbon and other nutrients.

Leaves and other coarse particulate detritus from streamside forests are readily used as food by macroinvertebrates (Cummins et al. 1989). Tributaries flowing through forested areas or having well developed riparian canopies continuously receive organic detritus throughout the year.

Most of the biological activity in stream ecosystems takes place on inorganic and organic substrates on the surface of or within the benthic (bottom) area of the channel (Sweeney 1993). Existing data strongly suggest that streamside forests greatly increase the amount and complexity of benthic habitat available for colonization by macroinvertebrates. Surface area for macroinvertebrates is continuously added to streams in the form of woody debris shed from the streamside forest (tree twigs, branches, whole trunks). This debris provides surface area of a different texture from that of roots or rocks and has an additional dimension (interior) for benthic organisms to use for various stages of their life histories. At periodic intervals, the accumulating woody debris forms small dams that add local habitat variety, such as depth and flow (Triska and Cromack 1981).

White Clay Creek, Pennsylvania, provides an example of the importance of riparian vegetation to macroinvertebrate populations. The presence or absence of a forest along sections of its channel affected the amount of exposed surface available for colonization by benthic organisms (Sweeney 1993). A forested second-order channel contained substantially more woody debris, in terms of both number and volume of woody pieces, than a contiguous meadow reach. Although the amount of additional surface area varied according to the nature and extent of the riparian forest, this section of White Clay Creek had an average of 4.73 m^2 of surface area (in the form of woody debris) added per 25 m of channel length. For a coastal plain stream in Virginia, Smock, Metzler, and Gladden (1989) found that benthic areas covered with woody debris dams contained an annual average of about 22,302 macroinvertebrates per square meter.

Numerous studies have shown that streams with woody debris are generally more retentive of particulate organic matter than streams without wood (Bilby and Likens 1980; Bilby 1981; Speaker, Moore, and Gregory 1984; Golladay, Webster, and Benfield 1987; Bilby and Ward 1989; Webster et al. 1988). Thus, macroinvertebrates specializing in either eating woody debris or using it as substrate for attaching larval retreats or nets, building larval cases, or laying eggs will be severely limited in meadow reaches of streams. These limitations include the lack of direct particulate woody input, the limited amount of input from upstream forested reaches, and the possibility that narrow meadow channels have less retention capacity for particulate organic material if or when it might enter the channel (Sweeney 1993).

The woody roots of trees growing close to the stream provide additional surface for macroinvertebrate colonization (Figure 10) (Rhodes and Hubert 1991). Tree roots have an extremely high surface area to volume ratio, can persist for a long time, and provide habitat for a variety of macroinvertebrate species. In contrast, roots of herbaceous plants, such as grasses along meadow streams, are very fine and provide poor habitat, because they quickly collect silt particles to form sod or break off readily in strong current (Sweeney 1993).

Figure 10. Exposed woody roots of riparian vegetation provide important refuge and colonization areas for macroinvertebrates

Tree roots in streams on the coastal plain of eastern North America show significant macroinvertebrate colonization (Sweeney 1993). In the Upper Three Runs of Aiken County, South Carolina, tree roots along the streambank contained 2,000 or more macroinvertebrates per 0.06 m^2 of root mat throughout most of the year, whereas densities of macroinvertebrates on mudflats of bare streambanks were always less than 1,000 per 0.06 m^2. The large difference between macroinvertebrate densities in these two benthic habitats means that streamside trees can substantially increase the standing stock of macroinvertebrates per unit length of stream channel.

Tree roots are prime substrata for collecting a diversity of aquatic insects in large numbers (Sweeney 1993). Rhodes and Hubert (1991) described streams in Wyoming where exposed root filaments of banks represented only 8.5 percent of total habitat but contained an estimated 44 percent of the total aquatic insect fauna in July and 30 percent in August. In some small coastal plain streams of the eastern United States, the roots from streamside trees have created the majority of debris dam sites for organic matter accumulation, and these debris dams support 10 to 15 times the density and biomass, respectively, of macroinvertebrates relative to sites without debris (Smock, Metzler, and Gladden 1989).

Although streamside vegetation is considered necessary to control water temperature and provide optimal fish habitat (Swanson, Fredrickson, and McCorison 1982, Platts 1983), at least two studies have indicated that macroinvertebrate populations are less abundant in shaded streams of the northwestern United States (Hawkins, Murphy, and Anderson 1982). Studies by Carlson, Andrus, and Froehlich (1990) indicated that macroinvertebrate communities were most abundant in streams that were shaded less by surrounding

vegetation, and Hawkins, Murphy, and Anderson (1982) found that canopy type was more important than substrate character in influencing total abundance and guild structure of macroinvertebrates in Oregon streams. However, existing data from the northeastern United States strongly suggest that streamside forests greatly increase the amount and complexity of benthic habitat available to macroinvertebrates (Sweeney 1993). The canopy of trees growing on opposite banks of a small stream will form a complete vegetative bridge that provides shade during appropriate seasons, while the streamside trees provide woody debris and roots that are readily colonized by macroinvertebrates. Sweeney (1993) estimated that deforested reaches along White Clay Creek in Pennsylvania had 50 percent less potential benthic habitat than those with riparian vegetation.

Recreation and Aesthetics

Introduction

The vast majority of the public served by the USACE live in urban areas. While the habitat benefits afforded by vegetation associated with flood control projects in urban environments can be substantial, the aesthetic and recreational benefits may, in fact, be the most significant.

Public use of USACE facilities (primarily for recreation) provides a remarkable opportunity to emphasize the capabilities of the organization and its commitment to serving the public through a strong environmental ethic. Thus, the educational and promotional benefits of environmentally sensitive flood control projects should not be overlooked.

Recreation considerations

Recreation activities associated with flood control projects include fishing, hunting, hiking, jogging/walking, bicycling, bird watching, and canoeing/rafting. The number of enthusiasts involved in these pursuits is overwhelming, and a flood control project that is designed to address recreational requirements will undoubtedly receive considerable use.

A review of the recreational activities listed above and others that might be exploited reveals that many are incompatible. Thus, an integrated form of land use can only be developed between a few recreational activities, ecological conservation, and the flood control purposes of a project.

Conservationists, thinking of preserving a habitat, might be tempted to say that any recreational pressure was bound to be adverse to the environment. However, almost all populations can be exploited, and that a population that is being underexploited is being mismanaged. Hunting, for example, is a resource-based recreational activity, and hence any over-exploitation will imply that there is a decrease in the recreational experience, and it is in the interests of the

recreational user to conserve the populations. Thus, the aims of a wildfowler and a biological manager wishing to preserve a population of wildfowl are very similar, and the two forms of land use can be integrated provided that a control system on the shooting can be established and implemented.

Sponsors of USACE flood control projects frequently desire the development of at least some recreational features in association with flood control projects. In some cases, these requests can be incorporated into the actual project design. More often, recreational development is undertaken by the sponsor and succeeds construction of the actual flood control facilities. Full advantage of the opportunity for sponsors to incorporate features can be realized only if they are planned for in the design of the flood control facilities.

Vegetation can play several roles in the attainment of recreational benefits from a site. As discussed in the preceeding section, vegetation is critical to wildlife and, thus, bird watching, hunting, and fishing are dependent upon the proper incorporation of vegetation into the design. In instances where facilities such as ball parks and bike paths are placed within the floodplain, vegetation can provide a visual screen and/or a physical barrier to separate areas for use.

It is inevitable that visitors will want to see some of the scientific and engineering interests of the area, and it is also useful to educate such people with the ideas and rationale that went into the design of the project. Simple measures such as the posting of signs describing the project and its features can go a long way toward educating the public and heightening the awareness of the services provided by the USACE.

Aesthetics

Aesthetics is another major reason for revegetation. Taller vegetation (e.g. shrubs and trees) can be used to screen views of objectionable areas. Vegetation can also be used to draw attention to features. A vegetative cover is generally viewed as more aesthetically pleasing than exposed soil; flowering woody and herbaceous vegetation is preferred over grass; and complex configurations of diverse vegetation species is preferred to homogeneous stands. This conjecture, as well as the others implicit in the rejection of preference is not only testable; it has been tested many times.

In reacting to the visual environmental, people seem to relate to the information they pick up in two quite different ways. They react both to the visual array, the two-dimensional pattern, as if the environment in front of them were a flat picture, as well as to the three-dimensional pattern of that unfolds before them. The idea of the visual array is easiest to think of in terms of a photograph of any given landscape. The pattern of light and dark on the photograph, the organization of this "picture plane," constitutes the basis of this level of analysis.

Complexity is the "involvement" component at this surface level of analysis. Perhaps more appropriately referred to as "diversity" or "richness," this component was at one time thought to be the sole or at least the primary

determinant of aesthetic reactions in general. Loosely speaking it reflects how much is "going on" in a particular scene, how much there is to look at. If there is very little going on as, for example, a scene consisting of an undifferentiated grassed floodplain, then preference is likely to be low.

A species has not only to be able to recognize the sorts of environments it functions well in, it has to prefer them. Animals have to like the sort of settings in which they thrive. Ideally. they would not have to learn such an inclination. It could be costly for an animal to spend years barely subsisting in unsatisfactory environments to learn that such environments were in fact unsatisfactory. Likewise, humans must prefer the visual environment associated with flood control projects for them to fully utilize them for recreation. Careful landscape planning and the incorporation of select vegetation to accomplish these objectives is critical.

Vegetation species providing recreation and aesthetic benefits are generally the same as those used for wildlife benefits. Aside from the obvious desire to avoid using species that cause irritation, such as poison ivy, or injury, such as thorny species, the list provided in the previous section can be used as the basis for selecting species for recreational and aesthetic uses.

Channel Stability Considerations

Introduction

The use of vegetation, primarily grasses and forbs, for the prevention of surficial erosion on slopes is fairly common. Biostabilization techniques to reinforce slopes and streambanks, popular in the 1930's in the United States, have seen a resurgence in recent years here and in southeast Asia and have been used for centuries in Europe. The role that vegetation plays in this application is fairly well understood, although there are many aspects left to learn. Considerably less understood and quantified is the impact of vegetation on sediment transport and deposition and its role in influencing channel morphology.

Because vegetation undoubtedly plays a major role in the morphological processes occurring within a channel and floodplain, its influence on channel stability should be considered during the project formulation and design. This section addresses the role of vegetation in the stabilization and protection of soil, its impacts on channel morphology, and its impacts on the sedimentation processes.

Soil stabilization characteristics of vegetation

The stabilizing benefits of vegetation can be a strong inducement for their incorporation into flood control projects. Leaves and stems of plants intercept rainfall and reduce surface erosion both from runoff and from overbank flooding. Vegetation, primarily woody plants, also helps to prevent mass movement,

particularly shallow sliding in slopes. Woody vegetation can influence slope stability through several mechanisms including:

a. Root reinforcement

b. Soil moisture modification

c. Buttressing and arching

d. Surcharge

e. Root wedging

f. Windthrowing

The roots of many woody species reinforce soil particles and substantially improve the tensile strength of the underlying soil mass. A root-reinforced soil behaves as a composite material in which elastic fibers of relatively high tensile strength (roots) are embedded in a matrix of relatively plastic soil. Tractive forces between the roots and the soil add shear strength to the composite. Vertical root systems can also penetrate through the soil mantle into firmer strata below, thus anchoring the soil to the slope and increasing resistance to sliding.

Roots also modify the soil moisture content of the soil, thus increasing slope stability and eliminating geotechnical failures related to high pore water pressure. Compared with unvegetated streambanks, soils in vegetated banks are much drier and better drained. Anchored and embedded stems can act as buttress piles or arch abutments in a slope, counteracting shear stresses and preventing soil sliding around and between vegetation components. The weight or surcharge of large trees exerts a stress component perpendicular to the slope which tends to increase resistance to sliding.

The downslope component of stress imparted from surcharge can also have a destabilizing influence on the slope, however, and this must be weighed against its benefits. Likewise, there are other destabilizing influences of vegetation. Of generally minor concern is the alleged tendency of roots to invade cracks, fissures, and channels in a soil or rock mass and thereby cause local instability by wedging or prying action. Of greater concern is the destabilizing influence from turning moments exerted on the soil mass as a result of strong winds or flowing water moving across the vegetation. This can become particularly troublesome when the turning forces are sufficient to uproot the vegetation and expose the underlying soil to further erosion.

Thus, the effect of vegetation on soil stability is the sum of the root reinforcement, soil moisture modification, and buttressing benefits minus the root wedging and overturning drawbacks, with consideration for both the stress components of surcharge. The net effect of these contributing forces is nearly always positive. Gray and Leiser (1982) present computational methods to evaluate the net impact of vegetation on slope stability.

Impacts on channel morphology

Recent studies of the hydraulic geometry of natural channels have highlighted the importance of bank vegetation in affecting bank processes and width adjustment (Thorne 1990). The soil and slope stabilizing benefits described above contribute significantly to the prevention of lateral migration of bank lines because of erosion. Generally, however, the benefits of vegetation in resisting bank erosion are temporally limited. Witness the thousands of streams that, despite the presence of bank vegetation, have managed to meander across the entire floodplain over geologic time. Nevertheless, vegetation can play a significant role in influencing bank line morphology, at least over engineering time.

The Platte River in Nebraska also provides an example of how live vegetation within the channel can significantly influence channel morphology. The Platte River is a wide, shallow braided stream that is characterized by large, periodic, and geometrically distinct bedforms called macroforms. Macroforms have dimensions commensurate with the width and depth of the channel and are emergent at all but the highest flow stages.

Since the development of irrigation, channel patterns on the Platte River have been changed by the establishment of vegetation on the macroforms. Their subsequent conversion to islands as vegetation-induced sediment deposition builds the macroform elevation and the stabilizing influence of the vegetation prohibits erosion of the islands. In the reach from North Platte to Kearney, NE, the formerly broad open channel has been transformed at many locations into a series of small, incised channels intertwining among islands of various sizes. According to the USGS, in 1860 the width of the Platte River ranged from 1,150 m (3,770 ft) at Cozad, NE, to 1,480 m (4,850 ft) at Kearney, NE. In 1979, the width of the Platte River from Cozad to Kearney ranged from 100 to 250 m (330 to 820 ft).

Aside from the influence of vegetation on the deposition of sediments, dense vegetation stands in the floodplain can affect the floodplain morphology by influencing the location of natural bendway cutoffs. This effect on channel morphology can be appreciated by looking at historical aerial photographs of channels. Although abandoned channels frequently become vegetated, seldom will a new channel establish itself through a dense stand of woody vegetation.

Channel width, depth, and slope are determined to a large degree by bank stability. Erodible banks allow adjustment of the channel width, depth, and sinuosity. As the channel moves within the floodplain to optimize gradients, for example, erosion allows a change in channel course into the bank and a widening of the channel. Cross-sectional area of the channel is maintained, and the width-to-depth ratio is increased. The channel slope is decreased when eroded material is deposited either on bars that increase channel sinuosity or in downstream reaches. Stabilization of banks helps to constrain movements of the channel and stabilizes the channel morphology.

Vegetation stabilizes banks by reducing erosive forces on the bank, decreasing erodibility of bank materials, and adding structural support to the bank.

Effects of vegetation on soil stability are the protection of soil surfaces from erosive forces, root reinforcement, soil moisture modification, and buttressing benefits counteracted by root wedging and plant overturning drawbacks. The net effect of these contributing forces is generally positive. Comparison of streambanks or slopes that have good vegetative cover with those that do not show the stabilizing benefits of vegetation to the soil. The stabilizing benefits of vegetation can be a strong inducement for their incorporation into flood control projects.

The morphology of channels are dictated by numerous variables that are complex and interrelated. The roles that vegetation play are not well understood but are certainly important.

Impacts on sedimentation

Vegetation plays a central role in the deposition of sediments on streambanks and floodplains. The capacity of flowing water to transport bed material load increases approximately with the sixth power of the velocity. As discussed in the preceding chapter, vegetation dramatically retards near bed and bank velocities by increasing the local flow resistance. This effect can and does promote deposition of the bed material load, particularly on streambanks.

Because of its ability to damp turbulence and to act as a filter, vegetation is also effective in trapping sediments carried as wash load. Along most forested floodplains, berms of material deposited within and behind particularly dense stands of vegetation are evident. These berms are formed when flood-borne wash load is deposited as the vegetation reduced local turbulence and filtered sediment. These berms are critical to the evolution of floodplain ecosystems as the successional development of vegetation is often influenced by minor variations in topography. The minor elevation changes afforded by floodplain berms are critical to the development of many riparian wetlands.

Vegetation stability

The stability criteria for vegetated channels can be stated in a number of ways, but each relates to the point at which the vegetation completely fails leading to possible failure of the underlying material. Five methods to evaluate the stability of a grass-lined channel have been proposed: maximum permissible velocity, maximum permissible depth, equivalent stone size, permissible tractive force, and maximum permissible deflection. Only the method based on maximum permissible velocities is based on direct observations. Each of these methods is discussed briefly (Kouwen, Li, and Simons 1980).

a. *Maximum Permissible Velocity (V_{max}).* Fortier and Scobey (1926) are often quoted as the source of values for maximum permissible velocities in bare earth channels. Their recommendations have been widely applied and accepted. Obviously, in vegetated channels, velocities near the bed are greatly reduced as a result of the drag on the vegetation stems. Thus, for an equal velocity of flow near the soil-water interface, it is possible to

have a much higher mean velocity of flow for a vegetated channel. Work by Cox and Palmer (1948) and Ree and Palmer (1949) summarized in Table 6 provides allowable velocities for channels lined with grass. Unfortunately, this information provides little insight into the allowable velocities for channels and floodplain vegetated with species other than grass. Recent laboratory studies at Utah State suggest that for many species of shrubs, velocities in excess of 3 fps may cause excessive erosion of underlying soils.

Table 6
Permissible Velocities for Channels Lined with Vegetation[1] (The values apply to average, uniform stands of each type of cover)

		Permissible Velocity	
Cover	Slope Range, %	Erosion Resistant Soils, fps[2]	Easily Eroded Soils, fps[2]
Bermuda grass	0-5	8	6
	5-10	7	5
	over 10	6	4
Buffalo grass	0-5	7	5
Kentucky bluegrass	5-10	6	4
Smooth brome	over 10	5	3
Blue grama	0-5[3]	5	4
Grass mixture	5-10	4	3
Lespedeza sericea *Weeping lovegrass* *Yellow bluestem*	0-5[4]	3.5	2.5
Kudzu *Alfalfa* *Crabgrass* *Common lespedezad* *Sudangrass*[5]	0-5[6]	3.5	2.5

[1] Use velocities exceeding 5 fps only where good covers and proper maintenance can be obtained.
[2] To convert feet per second (fps) to meters, multiply by 0.3048.
[3] Do not use on slopes steeper than 10 percent except for side slopes in a combination channel.
[4] Do not use on slopes steeper than 5 percent except for side slopes in a combination channel.
[5] Annuals--used on mild slopes or as temporary protection until permanent covers are established.
[6] Use on slopes steeper than 5 percent is not recommended.

b. *Maximum Permissible Depth (d_{max}).* Normann (1975) describes the design concept of maximum permissible depth, which ensures the stability of any channel, whether unlined or lined with a nonrigid material such as vegetation, riprap, or artificial fibrous roving. Design charts of d_{max} versus channel slope S_o are given for particular linings and soil erodability. To provide a method to determine the stability of grass linings which is compatible with the d_{max} approach, Normann converted the maximum permissible velocities listed in Table 6 to values for maximum permissible depth. For a series of slopes, he found the

permissible velocity, then using published *n-vR* curves, found n and R to match n versus VR. Next, he set $d_{max} = R$ and plotted d_{max} versus slope for various types of vegetation.

c. *Equivalent stone size*: Parsons (1963) introduced the notion of an equivalent stone size to describe the resistance of vegetation to destruction by flowing water. Using Ree and Palmer's tabulation of allowable velocities, slopes and hydraulic radii, Parsons computed the stone sizes required to give the same bank protection. The equivalent sizes are reproduced in Table 7. This approach can give the designer familiar with the capability of stone protection an appreciation of the protective capabilities of a vegetative liner. It also permits a ready comparison of costs.

Table 7
Equivalent Stone Sizes for Bermudagrass Linings

Condition of Bermudagrass	Allowable Shear Stress, lb/sq ft[1]	Equivalent Stone Diameter, cm (in.)
Fair stand, short, dormant[2]	0.9	5 (2.0)
Good stand, kept short, dormant	1.1	5 (2.0)
Good stand, long, dormant[3]	2.8	14 (5.5)
Excellent stand, kept short, green	2.7	14 (5.5)
Good stand, long, green	3.2	17 (6.5)

[1] To convert lb/sq ft to kg/sq m, multiply by 4.88.
[2] Less than 13 cm (5 in.) high.
[3] Greater than 20 cm (8 in.) high.

d. *Permissible tractive force.* Because the actual removal of soil particles occurs when the force exerted on the particle exceeds the force resisting movement, it is more appropriate to base the stability criteria on local boundary conditions. Using a tractive force approach for this makes more sense than the permissible velocity approach, since it is difficult to relate local velocity to average velocity. However, for a vegetative-lined channel, the application of the tractive force approach becomes difficult.

e. *Maximum permissible deflection.* Since the drag exerted on the vegetation by the flowing water is proportional to u^2 for turbulent flow, much of the fluid shear is transferred to the vegetation at the tips where the velocity is greatest. As the velocity is greatly reduced at lower levels in the vegetation, the amount of shear transferred by the fluid toward the bed is greatly reduced, and if the vegetation is tall and stiff, a layer of virtually zero velocity gradient will exist.

As a result, the only shear acting on the soil is that required to reduce the residual velocity u_r to zero. The effective shear stress at the soil-water interface, τ_e, is:

$$\tau_e = \lambda y_d S_f \left[\left(1 - C_f\right) \left({}^{n_s}\!/_{n} \right)^2 \right]$$

where

τ_e = effective shear stress at the soil-water interface

λ = unit weight of water

y_n = depth of flow

S_f = friction slope

C_F = potential of the vegetative cover to dissipate turbulent eddies near the bed

n_s = Manning's n associated with the bare soil

n = the reachwise Manning's n

Thus, for a design problem this equation can be used to determine the effective shear on the soil and a check can be made as to whether the allowable tractive force for the soil is exceeded.

Summary

Philosophies vary on the extent to which riparian habitat reconstruction or development should copy or influence nature. At one extreme is the horticulturalist's wish to create colorful, interesting, and attractive habitats for people in urban settings, while at the other the nature conservationist is committed to developing and/or protecting quality natural habitats capable of sustaining a healthy and diverse ecosystem. One thing is certain, however; the use of vegetation within the floodway and along the riparian corridor is necessary whether it be for aesthetics in an urban floodway park, for the stabilization of streambanks, for the interception of polluted runoff, or for the establishment and umaintenance of habitat for a single species or a community.

Riparian corridors provide unique, high-value habitat that is in limited supply. In addition, riparian fringe areas provide the only "natural" setting for recreational enthusiasts in many urban areas. The structural complexity of riparian ecosystems, particularly in comparison with uplands in arid climates, provides many habitat requirements and adds to the landscape diversity of the regional geography. Society in general has demonstrated a willingness to accept the additional costs associated with the protection and enhancement of these resources.

Diverse vegetation is generally desirable in restoration projects because the project is likely to be more successful than less complex systems. This is true for a variety of reasons. On a site level, an increase in numbers of species means a greater array of environmental tolerances are represented. In addition, diversity of vegetation within a landscape increases wildlife value of an area by providing

required habitats for different life stages of animals, such as feeding, winter cover, and breeding (Davis 1993).

The minimum arrangement of food and cover in close proximity to one another for a species is termed juxtaposition. Food available in one area (opening, meadow, etc.) and cover (tree stand, shrubs, etc.) nearby constitute a habitat unit and clearly reduce the energy required for and the natural hazards associated with the search for food away from cover. A habitat unit is an abstract entity and is not always easily defined. Equally clear is that the expenditure of energy to search for food and cover cannot be greater than that obtained from the food source or the animal loses weight. Another term related to juxtaposition is interspersion which is the distribution of habitat units for a species over the landscape. The arrangement of stands to provide food and cover in a checkerboard pattern provides landscape diversity to meet the habitat requirements for a large number of species.

Maintenance of high-quality habitat of diverse character helps maintain the highest possible number of species. Diversification of habitat can be acquired by planting different types of herbaceous and woody vegetation. Mixtures of vegetation are better suited to take advantage of site diversity as well as providing better overall ground cover.

Woody vegetation offers needed cover, breeding sites for birds and mammals, and a variety of food. Many bird species that feed largely on the ground in grass or other open areas require trees for nest sites or observation posts. Trees and shrubs could be planted in shelterbelts and in clumps. Coniferous trees and shrubs should be used in addition to deciduous plants to obtain a more diverse pattern of vegetation.

The knowledge of the principles of plant ecology is a prerequisite to sound management of wildlife. In any large-scale, long-term attempt to modify plant life for the benefit of desirable wildlife, we must move within the natural current of the environment and take advantage of the basic laws of plant and animal life.

Maintaining a strip of "natural" vegetation along flood control channels will provide a substantial amount of habitat suitable for a number of terrestrial game species. The improved cover and forage would result in significant increases in pheasants, dove, quail, rabbits, and many nongame species in these areas. On larger streams, greenbelts could have a number of significant uses if their development was planned properly, including fishing, hunting, sightseeing, picnicking, camping, nature study, and canoeing.

The stabilizing benefits of vegetation can also be a strong inducement for their incorporation into flood control projects. Leaves and stems of plants intercept rainfall and reduce surface erosion both from runoff and from overbank flooding. The roots of many woody species reinforce soil particles and substantially improve the tensile strength of the underlying soil mass. Roots also modify the soil moisture content and can eliminate geotechnical failures related to high pore water pressure.

Riparian sites associated with flood control projects have often been so seriously altered that the original vegetation is no longer adapted to the disturbances. Thus attempts to restore the original complement of plants may not be practical. However, unless a grouping of plants similar to the original community can be established, aquatic and terrestrial resources may not be fully restored.

Objectives must be clearly defined and evaluated before undertaking any revegetation scheme. Such clarification will ensure that conflicting objectives can be discovered and reconciled. For instance, it may be that the objectives are either wholly or partly beyond the capacity of revegetation (e.g., erosion control of very unstable slopes). Different treatments are often required to correct separate problems - control surface erosion, eliminate bank slumping, provide shade to the stream, control weeds, and provide concealment for wildlife (Platts 1983).

Artificial revegetation is not the only means to reattain a satisfactory plant cover. Natural recovery can often occur if areas are protected from stressors that led to the destruction of vegetation. If a remnant composition of desirable plants exists, natural restoration may be most practicable. Artificial revegetation normally should not be employed unless satisfactory recovery cannot be achieved by natural means within an acceptable period. Most riparian shrubs and trees are capable of resprouting and can recover from extensive use. Nonsprouting species are slower to recover and may reappear erratically. A satisfactory seed source may exist, but seedbed conditions on disturbed sites are not always conducive to seedling establishment. Although protected sites may recover slowly at first, once soil surfaces stabilize, new plants often appear rapidly.

Regardless of how revegetation is accomplished, there are a number of factors that should be considered. Site conditions are important regardless of the region where revegetation occurs. On the other hand, there are aspects of mineral nutrition and plant adaptation peculiar to the arctic and subarctic regions which must be understood to ensure the success of a revegetation scheme. The relative merit of introduced versus native species should also be evaluated.

4 Summary and Conclusions

Riparian vegetation occurs along streams and rivers and contributes greatly to many riparian ecosystem functions that are highly valued by society. Riparian ecosystems occur at the interface between upland and riverine systems where much of the water, nutrients, and animals from a watershed converge. Riparian vegetation is influenced by these factors from both the upland and riverine ecosystems. An understanding of the ecology of the vegetation in these systems is helpful to understanding the role riparian vegetation plays in stabilizing stream morphology and hydrology, attenuating floods, improving water quality, and supporting wildlife.

Riparian Vegetation Ecology

The structure and function of vegetation of the humid riparian areas of the East differs from riparian vegetation in the arid West. Riparian systems in the East are often dominated by overland flow. Large, complex floodplains develop along eastern rivers and include a large percentage of wetlands by area. Plants in these areas must be adapted to periods and depth of inundation of sufficient duration that soils become anaerobic. Western riparian ecosystems, in contrast, have less surface water through the year. Plants in these areas must be adapted to accessing groundwater that can be very deep relative to rooting depths.

Riparian vegetation varies widely in type, size, and distribution. Grasses, shrubs, vines, and trees are all found in riparian areas, although an area is often dominated by one type of vegetation. Many plant species can occur in both riparian and adjacent uplands, but some species such as western willows have life history characteristics that depend on an association with a river to reproduce and grow. The age and distribution of vegetation often reflects the dynamics of the associated river. Rivers that meander through a floodplain over time, for example, often have vegetation in many phases of succession.

Distribution patterns of riparian vegetation also depend on the moisture gradients, fluvial geomorphic landforms, and stream gradients. Moisture gradients are determined by surface flooding as well as depth to the groundwater. As described above, these differences often relate to eastern and western riparian systems. Plants differ in their ability to withstand inundation and, as a consequence, become distributed within the riparian corridor along an elevation-hydrologic gradient. Similarly, for depth to groundwater in more arid systems,

plants differ in their ability to access groundwater with varying root depths. Many western plant species are restricted to riparian areas where groundwater is closest to the surface and can be accessed. Distributions of plants on fluvial geomorphic landforms such as bars and terraces are often associated with a moisture gradient. However, the energy of the river also affects the ability of plants to survive close to the river where current energies are greatest. Trees typically dominate vegetation along streams with greater than 4 percent slopes, because they can tolerate the high forces from currents and debris during floods.

Natural ecological processes occur in riparian areas that alter vegetation in space and with time. Vegetation is often tolerant of disturbances such as floods, fire, and landslides that occur on fairly predictable cycles in a given area. The plants often persist following disturbances of low intensity. The species associations change through time as site conditions change in a process called succession. For example, willow that colonizes a newly created sand bar is eventually replaced by other species that are in turn replaced by other species over time. Catastrophic disturbances can remove existing vegetation and the process of primary succession is set in motion. Disturbances and succession are desirable processes in natural systems because they aid in the maintenance of the system's characteristics. If the disturbance regime or succession of plant communities is changed, the ecosystem changes and may not be capable of sustaining itself into the future.

Environmental Benefits

As a result of their landscape position between upland and riverine ecosystems, riparian corridors are capable of intercepting the majority of surface water entering riverine systems and thereby affecting water quality in the majority of surface waters of the nation. The primary effects of vegetation on water quality are because of increased resistance and nutrient uptake.

Most chemicals and nutrients in river water are associated with suspended solids, both mineral and organic. The increased resistance to flow by riparian vegetation allows suspended solids to settle out of the water column. The associated chemicals and nutrients are also removed from the water column and can become incorporated into the soils. Improvements in water clarity are directly related to the residence time of the overbank river water in the riparian corridor.

Riparian vegetation is intricately involved with the natural cycles of nutrients. Vegetation takes up nutrients that become incorporated into plant materials. Leaves and fruits are consumed by animals. As the plants become dormant in the fall or die, plant material is returned to the soils. Decay processes that are mediated by microorganisms release the minerals back into forms once again available for plant uptake. Nitrogen and phosphorus are taken up by plants in the largest amounts relative to other nutrients. Plants, however, are only temporary reservoirs for nutrients. Only developing plant communities that are increasing in biomass are effective in removing significant amounts of nutrients from the environment.

Riparian vegetation can offset reductions in suspended solids in the water column by adding dissolved and particulate organic carbon. The detrial export from riparian ecosystems, however, is critical to support of ecosystems downstream.

Riparian corridors provide critical wildlife habitat in many landscape settings. There is access to water, refuge from predators in the plants, and a variety of food sources. A wide diversity of animal species utilize riparian corridors because of the interface between upland and riverine habitats and linear linkage between upstream and downstream parts of watersheds. On an area basis, far more animals utilize riparian areas than any other landscape feature.

Riparian vegetation provides support for many wildlife requirements. If food is not directly provided to an animal by plants in the form of leaves, fruit, or stems, the insects and other primary consumers of plant materials are a source of food. The plant structure provides areas for rest, nesting, breeding, and escape. Although these characteristics are not unique to riparian vegetation, the proximity of riparian vegetation to other habitats and availability of moisture increases their value for both aquatic and terrestrial animal species.

The value of riparian areas is related to their size and contiguity with other riparian areas. Small or narrow riparian zones do not have adequate structure to support many desirable animal species, particularly neotropical migratory birds. A minimum of a 100-m buffer around streams is often cited as adequate to support most riparian-dependent wildlife species. Riparian areas are most valuable that remain intact and form a continuous corridor for migration.

Riparian vegetation effects on water quality are often beneficial to aquatic fauna. Dissolved and particulate organic matter contributed to streams by riparian vegetation provide critical food sources for downstream ecosystems. Water is cooled in the summer as it passes through vegetated floodplains or under overhanging vegetation. Riparian vegetation helps maintain critical dissolved oxygen concentrations for aquatic fauna by modifying water temperatures and aiding mixing of oxygenated water from the surface into the water column.

Riparian vegetation affects hydraulic and hydrologic functions of streams and rivers in several ways. Maintenance of stream morphology is improved by the bank stabilization afforded by riparian vegetation. The vegetation minimizes erosion by resisting flow and binding and structurally supporting bank materials. In addition, stream morphology is stabilized by vegetation that stabilizes stream baseflow through interactions with the surface and groundwater inputs from the watershed. Water losses by evapotranspiration help dewater bank materials, minimizing bank failure. Stream morphology is affected by patterns of erosion and deposition. Rates of erosion and deposition generally are minimized in vegetated riparian systems because minimized bank erosion contributes less to the sediment load. Deposition often occurs in vegetated areas such as on newly colonized bars and within floodplains.

Flood attenuation is increased in vegetated riparian systems. As is the case for maintenance of stream morphology, the resistance of vegetation to flow is an

important attribute for flood attenuation. The area that vegetation presents to flow is proportional to resistance (measured as Manning's n) and effectiveness at reducing flow velocity. This presented vegetational area of vegetation increases directly with increased stem size and density, Trees are most effective at resisting flow. Resistance of riparian vegetation is difficult to estimate, because it is rarely evenly distributed throughout the area of interest. In addition, resistance of vegetation and degree of maturation can change seasonally.

The use of vegetation, primarily grasses and forbs, for the prevention of surficial erosion on slopes is fairly common. Resistance to flow and stability of vegetation are important considerations in the design of flood control projects. Plant species differ in their tolerance thresholds to flow above which they completely fail and are torn out of the ground. As with resistance, plant failure thresholds to flow are highly variable depending on the age and size of the plant. These thresholds can be measured directly and indirectly in a variety of ways.

References

Adams, P. C., and Viereck, L. A. (1992). "Multivariate analysis of woody plant succession on the Tanana River in interior Alaska." *Proceedings-Symposium on ecology and management of riparian shrub communities,* USDA Forest Service, 4-10, Sun Valley, ID.

Allen, D. R., and Marlow, C. B. (1992). "Effects of cattle grazing on shoot population dynamics of beaked sedge." *Proceedings: Symposium on ecology and management of riparian shrub communities.* USDA Forest Service, 89, Sun Valley, ID.

Anderson, B. W., and Ohmart, R. D. (1975). "Annual report: Vegetation management studies," U. S. Bureau of Reclamation, Denver, CO.

Anderson, D. G. (1970). "Effects of urban development on floods in northern Virginia," U. S. Geological Survey, Water Supply Paper 2001-C.

Baker, W. L. (1989). "Maco- and micro-scale influences on riparian vegetation in western Colorado," *Annals of the Association of American Geographers* 79, 65-78.

Bell, D. T. (1992). "Tree stratum composition and distribution in the streamside forest," *The American Midland Naturalist* 1, 35-46.

Bell, D. T., and Johnson, F. L. (1974). "Flood-caused tree mortality around Illinois reservoirs." *Trans. Ill. State Acad. Sci.* 67 (1), 28-37.

Bilby, R. E. (1981). "Role of organic debris dams in regulating the export of dissolved and particulate matter from a forested watershed," *Ecology* 62, 1134-1143.

__________. (1991). "Characteristics and function of large woody debris in stream draining old-growth, clear-cut, and second-growth forests in south-western Washington," *Canadian Journal of Fisheries and Aquatic Sciences* 48, 2499-2508.

Bilby, R. E., and Likens, G. E. (1980). "Importance of organic debris dams in the structure and function of stream ecosystems," *Ecology* 60, 1107-1113.

Bilby, R. E., and Ward, J. W. (1989). "Changes in the characteristics and functions of woody debris with increasing size of streams in western Washington," *Transactions of the American Fisheries Society* 118, 368-378.

Binns, N. A. (1979). "A habitat quality index for Wyoming trout streams," Fishery Research Report Monograph Series No.2, Wyoming Game and Fish Department, Cheyenne.

Blair. W. F. (1939). "Some observed effect of stream-valley flooding on mammalian populations in eastern Oklahoma," *Journal of Mammalogy* 20, 304-306.

Bliss, L. C., and Cantlon, J. E. (1957). "Succession on river alluvium in Northern Alaska," *The American Midland Naturalist* 58(2), 452-469.

Bloss, D. A., and Brotherson, J. D. (1979). "Vegetation response to a moisture gradient on an ephemeral stream in central Arizona," *Great Basin Naturalist* 39(2), 161-176.

Boldt, C. E., Uresk, D. W., and Severson, K. E. (1978). Riparian woodlands in jeopardy on the Northern High Plains." *National Symposium on Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems.* Callaway Gardens, Atlanta, GA.

Boussu, M. F. (1954). "Relationship between trout populations and cover on a small stream," *Journal of Wildlife Management* 18, 227-239.

Brinson, M. M. (1980). "Riparian and floodplain ecosystems: Functions, values, and management," U.S. Fish and Wildlife Service Biological Service Program, Washington, DC.

Brinson, Mark M. (1993). "Hydrogeomorphic classification for wetlands," WRP-TR-DE-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brinson, Mark M., Swift, Brian L., Plantico, Reuben C., and Barclay, John S. (1981). "Riparian ecosystems: Their ecology and status," U.S. Fish and Wildlife Service FWS/OBS-81/17.

Brinson, M. M., Hauer, F. R., Lee, L. C., Nutter, W. L., Smith, R. D., and Whigman, D. (1995). "Guidebook application of hydrogeomorphic assessments to riverine wetlands (operational draft)," TR-DE-11, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bryan, K. (1928). "Change in plant association by change in ground water level," *Ecology* 9(4), 474-478.

Bush, J. K., and Auken, O. W. (1984). "Woody-species composition of the upper San Antonio River gallery forest," *The Texas Journal of Science* 36(2&3), 139-148.

Carlson, J. Y., Andrus, C. W., and Froehlich, H. A. (1990). "Woody debris, channel features, and macroinvertebrates of streams with logged and undisturbed riparian timber in northeastern Oregon, USA," *Canadian Journal of Fisheries and Aquatic Sciences* 47, 1103-1111.

Chaney, E., Elmore, W., Platts, W. S. (1990). "Livestock grazing on western riparian areas," Produced for the U.S. Environmental Protection Agency by the Northwest Resource Information Center, Inc., Eagle, ID.

Clark, J. R., Benforado, J., ed. (1981). *Wetlands of bottomland hardwood forests,* Elsevier Science Publishing Co., Amsterdam.

Cody, M. L. (1974). *Competition and the structure of bird communities*, Princeton University Press, Princeton, NJ.

Cody, M. L. (1981). "Habitat selection in birds: The roles of habitat structure, competitors, and productivity," *Bioscience* 31, 107-113.

Conners, E. M., and Naiman, R. J. (1984). "Particulate allochthonous inputs: Relationships with stream size in an undisturbed watershed," *Canadian Journal of Fisheries aquatic Sciences* 41, 1473-1484.

Conard, S. G., MacDonald, R. L., Holland, R. F. (1977). "Riparian vegetation and flora of the Sacramento Valley." *Symposium on the Importance, Preservation, and Management of the Riparian Habitat*, Tucson, AZ.

Costello, D. F. (1981). *The prairie world*, 2nd ed., University of Minnesota Press, Minneapolis, MN.

Cox, M. B., and Palmer, V. J. (1948). "Results of tests on vegetated waterways and method of field application," Technical Bulletin No. MP-12, Oklahoma Agricultural and Mechanical College, Agricultural Experimental Station. Stillwater, Oklahoma.

Cummins, K. W., Wilzbach, M. A., Gates, D. M., Perry, J. B., and Taliaferro, W. B. (1989). "Shredders and riparian vegetation," *Bioscience* 39, 24-30.

Curtis, R. L., and Ripley, T. H. (1975). "Water management practices and their effect on nongame bird habitat values in a deciduous forest community, management of forest and range habitats for nongame birds," General Technical Report WO-1, D.R. Smith, ed., U.S. Department of Agriculture Forest Service, Washington, DC, 128-141.

Davis, M. (1993). "Meeting technical needs for wetland vegetation restoration," *Proceedings, National Wetlands Engineering Workshop, St. Louis, MO, 2-3 August 1993.* Technical Report WRP-RE-8, U.S. Army Corps of Engineer Waterways Experiment Station, Vicksburg, MS.

Dick-Peddie, W. A., and Hubbard, J. F. (1977). "Classification of riparian vegetation." *Importance, Preservation, and Management of Riparian Habitat; A Symposium.* U.S. Department of Agriculture Forest Service, Tucson, AZ.

Dickson, J. G., and Huntley, J. C. (1985). "Streamside management zones and wildlife in the Southern Coastal Plain, riparian ecosystems and their management: Reconciling conflicting uses," General Technical Report RM-120, R. R. Johnson, C. D. Ziebell, D. R. Patton, P. F. Folliott, and R. H. Hamre, ed., U.S. Department of Agriculture Forest Service, Washington, DC, 263-264.

Dickson, J. G., and Williamson, J. H. (1988). "Small mammals in streamside management zones in pine plantations, management of amphibians, reptiles, and small mammals in North America," General Technical Report RM-166, R. C. Szaro, K. E. Severson, and D. R. Patton, ed., U.S. Department of Agriculture Forest Service, Fort Collins, CO, 375-378.

Drury, W. H., and Nisbet, I. (1973). "Succession," *Journal of the Arnold Arboretum* 54, 331-368.

Dunne, T., and Leopold, L. B. (1978). *Water in environmental planning*, W. H. Freeman and Company, San Francisco, CA.

Elder, J. F., and Cairns, D. J. (1982). "Production and decomposition of forest litter fall on the Apalachicola River Floodplain, Florida, River quality assessment of the Apalachicola River Basin, Florida," Water-Supply Paper 2196, U.S. Geological Survey, Tallahassee, FL.

England, E. S., Foreman, L. D., and Laudenslayer, W. F., Jr. (1984). "Composition and abundance of bird populations in riparian systems of the California deserts," *California riparian systems: Ecology, conservation, and productive management.* R. E. Warner and K. M. Hendrix, ed., University of California Press, Berkley, 694-705.

Everitt, B. L. (1968). "Use of the cottonwood in an investigation of the recent history of a flood plain," *American Journal of Science* 266, 417-439.

Flanagan, L. B., Ehleringer, J. R., and Dawson, T. E. (1992). "Water sources of plants growing in woodland desert and riparian communities: Evidence from stable isotope analysis." *Proceedings: Symposium on ecology and management of riparian shrub communities*, General Technical Report INT-289, U.S. Department of Agriculture Forest Service, Boise, ID.

Fonda, R. W. (1974). "Forest succession in relation to river terrace development in Olympic National Park, Washington," *Ecology* 55(5), 927-942.

Fortier, S., and Scobey, F. C. (1926). "Permissible canal velocities," *Transactions, American Society of Civil Engineers 89*, Paper No. 1588, 940-984.

Fowells, H. A. (1965). "Silvics of forest trees of the United States," Agricultural handbook number 271, U.S. Forest Service, Lakes States Forest Experiment Station, St. Paul, MN.

Gaines, D. A. (1974). "Review of the status of the yellow-billed cuckoo in California," *Condor* 76, 204-209.

Glinski, R. L. (1977). "Regeneration and distribution of sycamore and cottonwood trees along Sonoita Creek, Santa Cruz County, Arizona," *Symposium on the importance, preservation and management of the riparian habitat*, RM-43, U.S. Department of Agriculture Forest Service, Fort Collins, CO.

Golladay, S. W., Webster, J. R., and Benfeld, E. F. (1987). "Changes in stream morphology and storm transport of seston following watershed disturbance," *Journal of the North American Benthological Society* 6, 1-11.

Gosselink, J. G., Lee, L. C., Muir, T. A., ed. (1990). *Ecological processes and cumulative impacts: Illustrated by bottomland hardwood wetland ecosystems.* Lewis Publishers, Inc., Chelsea, MI.

Gray, D. H., and Leiser, A. T. (1982). *Biotechnical slope protection and erosion control*, Van Nostrand Reinhold, New York, NY. Reprinted by Krieger Pub. Co., Melbourne, FL.

Gregory, S. V., Swanson, F. J., McKee, W. A., Cummins, K. W. (1991). "An ecosystem perspective of riparian zones," *Bioscience* 41, 540-551.

Gutzwiller, K. J., and Anderson, S. H. (1987). "Multiscale associations between cavity-nesting birds and features of Wyoming streamside woodlands," *Condor* 89, 534-548.

Hammer, Donald A. (1992). *Creating Freshwater Wetlands*, Lewis Publishers, Boca Raton, FL.

Hanson, D. L. (1977). "Habitat selection and spacial interaction in allopatric and sympatric populations of cutthroat and steelhead trout," Ph.D. diss., University of Idaho, Moscow.

Harms, W. R., Schreuder, H. T., Hook, D. D., Brown, C. L., and Shropshire, F. W. (1980). "The effects of flooding on the swamp forest in Lake Ocklawaha, FL," *Ecology* 61(6), 1412-1421.

Hawkins, C. P., Murphy, M. L., and Anderson, N. H. (1982). "Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams of Oregon," *Ecology* 63, 1840-1855.

Hecht, B. (1993). "South of the Spotted Owl: Restoration strategies for episodic channels and riparian corridors in central California." *Western wetlands: Proceedings-1993 Conference of SWS, Western Chapter. Society of Wetland Scientist*, 104-117.

Huffman, R. T., and Forsythe, S. W. (1981). "Bottomland hardwood forest communities and their relation to anaerobic soil conditions," *Wetlands of bottomland hardwood forests*, J. R. Clark and J. E. Clark, ed., Elsevier Science Publishing Co., Amsterdam, 187-196.

Hunt, R. L. (1976). "A long-term evaluation of trout habitat development and its relation to improving management-related research, " *Transactions of American Fisheries Society* 105, 361-365.

Hupp, C. R., and Osterkamp, W. R. (1985). "Bottomland vegetation distribution along Passage Creek, Virginia, in relation to fluvial landforms," *Ecology* 66(3), 670-681.

Johnson, R. R, Bennett, P. S., and Haight L. T. (1989). "Southwestern woody riparian vegetation and succession: An evolutionary approach." *Proceedings-California Riparian Systems Symposium.* Davis, CA. USDA Forest Service, 135-139.

Johnston, C. A. (1991). "Sediment and nutrient retention by freshwater wetlands: Effects on surface water quality," *Critical Reviews in Environmental Control* 21 (5,6), 491-565.

Junk, W. (1989). *Flood tolerance and tree distribution in central Amazonian floodplains*, L. B. Nielson, I. C. Balsley, and H. Holm, ed., Academic Press, Orlando, FL, 47-64.

Jurik, T. W., Wang, S., and van der Valk, A. G. (1994). "Effects of sediment load on seedling emergence from wetland seed banks," *Wetlands* 14, 159-165.

Karr, J. R., and Roth, R. R. (1971). "Vegetation structure and avian diversity in several new world areas," *American Naturalist* 105, 423-35.

Karr, J. R., and Schlosser, I. J. (1978). "Water resources and the landwater interface," *Science* 210, 229-234.

Kay, C. E., and Chadde, S. (1992). "Reduction of willow seed production by ungulate browsing in Yellowstone National Park." *Proceedings: Symposium on Ecology and Management of Riparian Shrub Communities.* Sun Valley, ID. USDA Forest Service.

Keller, C. M. E., Robbins, C. S., and Hatfield, J. S. (1993). "Avian communities in riparian forests of different widths in Maryland and Delaware," *Wetlands* 13, 137-144.

Kennedy, H. E., Jr. (1970). "Growth of newly planted water tupelo seedlings after floodings and siltation," *Forest Science* 16(2), 250-256.

Kouwen, N., Li, R., and Simmons, D. B. (1980). "A stability criteria for vegetated waterways," *International symposium on urban storm runoff* 203-210.

Kovalchik, B. L., and Elmore, W. (1992). "Effects of cattle grazing systems on willow-dominated plant associations in central Oregon." *Proceedings: Symposium on ecology and management of riparian shrub communities.* Sun Valley, ID. USDA Forest Service, 111-119.

Kozlowski, T. T. (1984a). "Plant responses to flooding of soil," *Bioscience* 34, 162-167.

__________. (1984b). *Flooding and plant growth.* Academis Press, Inc. New York, 356.

Krzysik, A. J. (1979). "Resource allocation, coexistence, and the niche structure of a streambank salamander community," *Ecological Monographs* 49, 173-194.

Landers, J. L., Hamilton, R. J., Johnson, A. S., and Marchinton, R. L. (1979). "Foods and habitat of black bears in southeastern North Carolina," *Journal Wildlife Management* 43, 143-153.

Lowe, C. H. (1964). *Arizona's natural environment,* University of Arizona Press, Tucson.

Lowrance, R., Tood, R., Fail, J., Jr., Hendrickson, O., Jr., Leonard, R., and Asmussen, L. (1984). "Riparian forests as nurtients filters in agricultural watersheds," *Bioscience* 34(6), 374-377.

McBride, J. R., and Strahan J. (1984). "Establishment and survival of woody riparian species on gravel bars of an intermittent stream," *The American Midland Naturalist* 112(2), 235-245.

Meehan, W. R., Swanson, F. J., and Sedell, J. R. (1977). "Influence of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply, importance, preservation, and management of riparian habitat," R. R. Johnson and D. A. Jones, ed., General Technical Report RM-43, U.S. Department of Agriculture Forest Service, Fort Collins, CO, 137-145.

Meinzer, O. E. (1927). "Plants as indicators of groundwater," U.S. Geological Survey Water Supply Paper 577.

Mitsch, W. J., and Gosselink, J. G. (1986). School of Natural Resources, The Ohio State University, Columbus, Ohio. *Wetlands: Chapter 16 Wetland Management and Protection,* New York: Van Nostrand Reinhold; 1986: 415-449.

__________. (1993). *Wetlands.* 2nd ed. Van Nostrand Reinhold, New York, NY.

Moring, J. R., Garman, G. C., and Mullen, D. M. (1985). "The value of riparian zones for protecting aquatic systems: General concerns and recent studies in Maine," General Technical Report RM-20, U.S. Department of Agriculture Forest Service, Fort Collins, CO.

Naiman, R. J., Decamps, H., and Pollock, M. (1993). "The role of riparian corridors in maintaining regional biodiversity," *Ecological Applications* 3(2), 209-212.

Nanson, G. C., and Beach H. F. (1977). "Forest succession and sedimentation on a meadering -river floodplain, northeast British Columbia, Canada," *Journal of Biogeography* 4, 229-251.

Niering, W. A. (1987). "Vegetation dynamics (succession and climax) in relation to plant community management," *Conservation Biology* 1(4), 287-295.

Nilsson, C. (1992). *Change in riparian plant community composition among two rivers in northern Sweden.* Elsevier Applied Science, Hansson, London, England, 352-72L.

Noble, M. G. (1979). "The origin of Populus deltoides and Salix interior zones on point bars along the Minnesota River," *The American Midland Naturalist* 102(1), 59-67.

Normann, J. M. (1975). "Design of stable channels with flexible lining," Hydraulic Engineering Circular No. 15, Federal Highway Administration, U.S. Department of Transportation, Wahsington, DC.

Odum, Eugene P. (1975). *Ecology.* Holt, Rinehart, and Winston, New York.

Odum, E. P. (1978). "Ecological importance of the riparian zone, Strategies for protection and management of floodplain wetlands and other riparian ecosystems," R. R. Johnson and J. F. McCormick, ed., General Technical Report WO-12, U.S. Department of Agriculture Forest Service, Washington, DC, 2-4.

Organ, J. A. (1961). "Studies of the local distribution, life history, and population dynamics of the salamander Genus Desmognathus in Virginia," *Ecological Monographs* 31, 189-200.

Parsons, D. A. (1963). "Vegetative control of streambank erosion," Agricultural Research Sedimentation Conference, Miscellaneous Publications No. 970, Paper 20, 130-136.

Patton, D. R. (1992). *Wildlife habitat relationships in forested ecosystems*, Timber Press, Portland, OR.

Pianka, E. R. (1967). "On lizard species diversity: North American flatland deserts," *Ecology* 50, 498-502.

Pickett, S. T. A., and White, P. S. (1985). *The ecology of natural disturbance and patch dynamics*, Academic Press, New York.

Pinay, G., Decamps, H., Chauvet, E., and Fustec, E. (1990). "Functions of ecotones in fluvial systems," *The ecology and management of aquatic-terrestrial ecotones*, R. J. Naiman and H. Decamps, ed., Parthenon Publishing Group, Carnforth, UK, 141-170.

Pinkney, F. C. (1992). "Revegetation and enhancement of riparian communities along the lower Colorado River," U.S. Department of Interior Bureau of Reclamation, Denver, CO.

Platts, W. S. (1983). "Vegetation requirements for fisheries habitats, managing intermountain rangelands – improvement of range and wildlife habitats," General Technical Report INT-157, Intermountain Forest and Range Experiment Station, U.S. Department of Agriculture Forest Service, Ogden, UT, 184-188.

Raedeke, K., ed. (1989). "Streamside management: Riparian wildlife and forestry interactions," Contribution Number 59, Institute of Forest Resources, University of Washington, Seattle, WA.

Rappole, J. H., and Warner, D. W. (1976). "Relationships between behavior, physiology and weather in avaian transients at a migratory stopover site," *Oecologia* 26, 193-212.

Ree, W. O., and Palmer, V. J. (1949). "Flow of water in channels protected by vegetative linings," U.S. Department of Agriculture. Soil Conservation Service Technical Bulletin No. 967, 115.

Reimhold, R. J., Hardisky, M. A., and Adams, P. C. (1978). "The effects of smothering a Spartina alterniflora salt marsh with dredged material," Technical Report D-78-38, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Reiser, D. W., and Bjornn, T. C. (1979). "Habitat requirements of anadromous salmonids," General Technical Report PNW-96, Pacific Northwest Forest and Range Experiment Station, U.S. Department of Agriculture Forest Service, Portland, OR.

Rhodes, H. A., and Hubert, W. A. (1991). "Submerged undercut banks as macroinvertebrate habitat in a subalpine stream," *Hydrobiologia* 213, 149-153.

Ritzi, R. W., Bouwer, H., and Sorooshian, S. (1985). "Water resource conservation by reducing phreatophyte transpiration," Tech. Rep. RM-120, 191-196, USDA Forest Ser., Washington, DC.

Robertson, P. A., Weaver, G. T., and Cavanaugh, J. A. (1978). "Vegetation and tree species patterns near the northern terminus of the southern floodplain forest," *Ecological Monographs* 48, 249-267.

Rochow, T. F. (1985). "Hydrologic and vegetational changes resulting from underground pumping at the Cypress creek well field, Pasco County, Florida," *Journal of the Florida Academy of Sciences* 48(2), 65-80.

Rood, S. B., and Mahoney, J. M. "Collapse of riparian poplar forests downstream from dams in western prairies: Probable causes and prospects for mitigation," *Environmental Management* 14 (4), 451-464.

Rosenzweig, M. L. (1973). "Habitat selection experiments with a pair of coexisting heteromyid rodent species," *Ecology* 54, 111-17.

Rosgen, D. L. (1994). "A classification of natural rivers," *Catena* 22, 169-199.

Rosgen, D. (1995). "Applied fluvial geomorphology course materials," Wildland Hydrology Consultants, Pagosa Springs, CO.

Rudolph, D. C., and Dickson, J. G. (1990). "Streamside zone width and amphibian and reptile abundance," *Southwestern Naturalist* 35, 472-476.

Sands, A., and Howe, G. (1977). "An overview of riparian forests in California: Their ecology and conservation." *Symposium on the Importance, Preservation, and Management of the Riparian Habitat*, Tucson, AZ.

Schlosser, I. J., and Karr, J. R. (1981). "Riparian vegetation and channel morphology impact on spatial patterns in water quality in agricultural watersheds," *Environmental Management* 4, 233-243.

Scott, J. (1980). "The beleaguered blues," *Colorado Outdoors* 29, 1-3.

Segelquist, C. A., Scott, M. L., and Auble, G. T. (1993). "Establishment of populus deltoides under simulated alluvial groundwater declines," *The American Midland Naturalist* 130, 274-285.

Sharitz, R. R., and Lee, L. C. (1985). "Limits on regeneration processes in southeastern riverine wetlands," U.S. Department of Agriculture Forest Service Gen. Tech. Rep. RM-120: 139-143, Washington, DC.

Shaw, N. L. (1992). "Recruitment and growth of pacific willow and sandbar willow seedlings in response to season and intensity of cattle grazing." *Proceedings: Symposium on ecology and management of riparian shrub communities*, USDA Forest Service, Sun Valley, ID.

Smith, H. L., and Leopold, L. B. (1942). ""Infiltration studies in the Pecos River watershed, New Mexico and Texas," *Soil Science* 53, 195-204.

Smock, L. A., Metzler, G. M., and Gladden, J. E. (1989). "Role of debris dams in the structure and functioning of low-gradient headwater streams," *Ecology* 70, 764-775.

Speaker, R., Moore, K., and Gregory, S. (1984). "Analysis of the process of retention of organic matter in stream ecosystems," *Verhandlungen der Internationalen Vereinigung fur Theoretische und Angewandte Limnologie* 22, 1835-1841.

Stabler, D. F. (1985). "Increasing summer flow in small streams through management of riparian areas and adjacent vegetation: A synthesis," Tech. Rep. RM-120, 206-210, USDA Forest Serv., Washington, DC.

Stauffer, D. F., and Best, L. B. (1980). "Habitat selection by birds of riparian communities: Evaluating effects of habitat alterations," *Journal of Wildlife Management* 44(1), 1-15.

Stevens, L. E., Brown, B. T., Simpson, J. M., and Johnson, R. R. (1977). "The importance of riparian habitat to migrating birds, importance, preservation, and management of riparian habitat," R. R. Johnson and D. A. Jones, ed., General Technical Report RM-43, Rocky Mountain Forest and Range Experiment Station, U. S. Department of Agriculture Forest Service, Fort Collins, CO, 156-164.

Stevens, L. E., and Waring, G. L. (1985). "The effects of prolonged flooding on the riparian plant community in Grand Canyon, riparian ecosystem and their management: Reconciling conflicting uses," Tucson, Arizona, USDA Forest Service, 81-86.

Stromberg, J. C., Richter, B. D., Patten, D. T., and Wolden, L. G. (1993). "Response of sonoran riparian forest to a 10-year flood, " *Great Basin Naturalist* 53(2), 118-130.

Swanson, F. J., Fredrickson, R. L., and McCorison, F. M. (1982). "Material transfer in a western Oregon forested watershed, analysis of coniferous forest ecosystems in the western United States," R. L. Edmonds, ed., Hutchinson Ross, Stroudsburg, PA, 233-266.

Sweeney, B. W. (1993). "Effects of streamside vegetation on macroinvertebrate communities of White Clay Creek in eastern North America." *Proceedings of the Academy of Natural Sciences of Philadelphia* 144, 291-340.

Swenson, J. E. (1979). "Factors affecting status and reproduction of ospreys in Yellowstone National Park," *Journal of Wildlife Management* 43, 595-601.

Sykes, K. J., Perkey, A. W., and Palone, R. S. (1993). "Crop tree management in riparian zones. Riparian Ecosystem in the Humid U.S.: Functions, Values, and Management," National Association of Conservation Districts, Atlanta, GA.

Tabacchi, E. A., Planty-Tabacchi, A. M., and Dechamps, O. (1990). "Continuity and discontinuity of the riparian vegetaion along a fluvial corridor," *Landscape Ecology* 5, 9-20.

Taylor, J. R., Cardamone, M. A., and Mitsch, W. J. (1990). "Bottomland hardwood forests: Their functions and values, ecological processes and cumulative impacts," Illustrated by bottomland hardwood wetland ecosystems, J. G. Gosselink, L. C. Lee, and T. A. Muir, ed., Lewis Publishers, Chelsea, MI, 13-81.

Teskey, R. O., and Hinckley, T. M. (1978). "Impact of water level changes on woody riparian and wetland communities, Northern Forest Region," Fish and Wildlife Services, U. S. Department of the Interior, 5, 1-54.

Teversham, J. M., and Slaymaker, O. (1976). "Vegetation composition in relation to flood frequency in Lillooet River Valley, British Columbia," *Catena* 3, 191-201.

Theriot, R. F. (1993). "Flood tolerance of plant species in bottomland forests of the southeastern United States," Technical Report WRP-DE-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Thomas, J. W., Maser, C., and Rodiek, J. E. (1980). "Riparian zones," *Wildlife habitats in managed forests: The Blue Mountains of Oregon and Washington.* Handbook 533, J. W. Thomas, ed., U.S. Department of Agriculture Forest Service, Washington, DC, 40-47.

Thomas, William A. (Unpublished Draft 1994). "Methods for predicting n-values for the Manning equation," (Technical Report in preparation), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Thorne, C. R. (1990). "Effects of vegetation on riverbank erosion and stability." *Vegetation and Erosion.* Wiley, New York, 125-144.

Tilley, S. G. (1973). "Life histories and natural selection in populations of the salamander Desmognathus ochrophaeus," *Ecology* 54, 3-17.

Triska, F. J., and Cromack, K., Jr. (1981). "The role of wood debris in forests and streams." *Forests: Fresh perspectives from ecosystems analysis*, R. H. Waring, ed., Oregon State University Press, Corvallis, 181-190.

Trush, W. J., Connor, E. C., and Knight, A. W. (1989). "Alder establishment and channel dynamics in a tributary of the South Fork Eel River, Mendocino County, California," California riparian systems conference. PSW-110, U.S. Department of Agriculture Forest Service, San Diego, CA.

U.S. Army Engineer Division, New England. (1991). "Buffer strips for riparian zone management (A literature review)," Section 22, Vermont.

U.S. Fish and Wildlife Service. (1981). "Development of woody vegetation, The Platte River ecology study, special research project," Jamestown, ND.

USDA Soil Conservation Service. (1994). "Streambank and shoreline protection." *Engineering Field Handbook*, 650.

Walker, K. F., Thomas, M. C., and Sheldon, F. (1992). *Effects of weirs on the littoral environment of the River Murray, South Australia*, J. B. Thornes, P. J. Calow, P. Petts, and G. E. Boon, ed., Wiley New York, 271-292.

Ware, G. H., and Penfound, W. T. (1949). "The vegetation of the lower levels of the floodplain of the South Canadian River in Central Oklahoma," *Ecology* 30(4), 478-484.

Wauer, R. H. (1977). "Significance of Rio Grande riparian systems upon the avifauna, Importance, preservation and management of riparian habitat," R. R. Johnson and D. A. Jones, ed., General Technical Report RM-43, Rocky Mountain Forest and Range Experiment Station, U.S. Department of Agriculture Forest Service, Fort Collins, CO, 165-174.

Weaver, J. E. (1968). *Prairie plants and their environment.* University of Nebraska Press, Lincoln and London.

Webster, J. R., Benfield, E. F., Golladay, S. W., Kazmierczak, R. F., Jr., Perry, W. B., and Peters, G. T. (1988). "Effects of watershed disturbance on stream seston characteristics." *Forest hydrology and ecology at Coweeta.* W. T. Swank and D. A. Cossley, Jr., ed., Springer-Verlag, New York, 279-296.

Wesche, T. A., Goertler, C. M., and Frye, C. B. (1987). "Contribution of riparian vegetation to trout cover in small streams," *North American Journal of Fisheries Management* 7, 151-153.

Wharton, C. H., Kitchens, W. M., and Sipe, T. W. (1982). "The ecology of bottomland hardwood swamps of the Southeast: A community profile," FWS/OBS-81/37, U. S. Fish and Wildlife Service, Washington, DC.

Whitlow, T. H., and Harris, R. W. (1979). "Flood tolerance in plants: A state-of-the-art review," Technical Report E-79-2, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Willson, M. F., and Carothers, S. W. (1979). "Avifauna habitat islands in the Grand Canyon," *Southwestern Naturalist* 24, 563-576.

Young, P. J., Keeland, B. D., and Sharitz, R. R. (1995). "Growth and response of baldcypress [Taxodium Distichum (L.) Rich.] to an altered hydrologic regime," *American Midland Naturalist* 133, 206-212.

Young, W. J. (1991). "Flume study of the hydraulic effects of large woody debris in lowland rivers," *Regulated Rivers: Research and Management* 6, 203-211.

Youngblood, A. P., Padgett, W. G., and Winward, A. H. (1985). "Riparian community type of classification of eastern Idaho-Western Wyoming," R4-Ecol-85-01, U.S. Department of Agriculture Forest Service Intermountain Region, Boise, ID.

Appendix A
A Compilation of Woody and Herbaceous Species Commonly Found in Riparian Systems

Table A1

Scientific Name	**Common Name**	**Riparian Zone**[1]	**Value**	**Reference**	**Local**
		WOODY SPECIES			
Abies amabilis	Pacific silver	MMF	aesthetics	Brinson 1993	NW
Abies balsamea	Balsam fir	MLF	timber, wildlife, aesthetics	Sykes, Perky and Palone 1993	N,NW
Acacia greggii	Catclaw	AET		Johnson, Bennett, and Haight 1989	SW
Acer macrophylum	Big-leaf maple	MMF	aesthetics	Trush, Connor, and Knight 1989	W,NW
Acer negundo	Box elder	MMF	wildlife	Sands & Howe 1977, Sykes, Perky, and Palone 1993	N,C, NW
Acer saccharinum	Silver maple	MHF	timber, wildlife, aesthetics	Sykes, Perky and Palone 1993	S,NE,C
Acer saccharum	Sugar maple	MHF	timber, wildlife, aesthetics	"	N,NE,C
Acer rubrum	Red maple	MHF	timber, wildlife, aesthetics, water quality	"	SE,NE
Aeseulus glabra	Buckeye	MMF	timber	Brinson 1993	NW,N

(Sheet 1 of 10)

[1]Riparian zone modifers for vegetation

East and Pacific Northewest
MLF-Mesic low floodplain
MMF-Mesic medium floodplain
MHF-Mesic high floodplain
MTF-Mesic transitional floodplain

West
AEC-Arid ephemeral channel
AET-Arid ephemeral transition
AIC- Arid intermittent channel
AIF-Arid intermittent floodplain
AIT-Arid intermittent transition
APC-Arid perennial channel
APF-Arid perrennial floodplain
APT-Arid perennial transition

Table A1 (Continued)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference	Local
WOODY SPECIES (Continued)					
Aesculus octandra	Yellow buckeye	MHF	timber	Sands & Howe 1977	E, N
Allanrolfea occidentalis	Iodine bush		wildlife	Dick-Peddie & Hubbard 1977	C,W
Alnus oblongifolia	Alder	MMF	timber (west) wildlife (east)	Sykes, Perky, and Palone 1993	NW
Alnus rugosa	Speckled alder	MMF		Brinson 1993	NW
Alnus tenuiflolia	Thin-leafed alder	AIF	wildlife, aesthetics	Dick-Peddie & Hubbard 1977	SW
Aloysia grattisima	White brush	AIT		Brush and Auken 1984	S
Amorpha fructicosa	False indigo-bush	MFS			C
Ampelopsis arborea	Peppervine	AIT		"	C
Artemisia douglasiana		AIT		Conard, MacDonald, and Holland 1977	W
Atriplex sp.	Shadescale	AET		Pinkney 1992	W
Baccharis emoryi	Baccharis	AET		"	W
Baccharius salicina	Great Plains false willow	MMF			C
Baccharis sarothroides	Desert broom	AET		Sands & Howe 1977	W
Baccharius viminea	Mulefat	AIT		"	W
Betula alleghaniensis	Yellow birch	MMF	timber	Sykes, Perky, and Palone 1993	N,NE
Betula fontinalis	Birch	MHF		"	SW
Betula nigra	River birch	MMF	timber, aesthetics	"	NE
Betula papyrifera	Paper birch	MHF	timber,aesthetics	"	NE
Betula populifolia	Grey birch	MHF	wildlife	"	NE
Brickella laciniata	Brickel brush	AET		Dick-Peddie & Hubbard 1977	W
Bumelia lanuginosa	Gum bumelia	MHF	aesthetics	Bush and Auken 1984	SW
Campsis radicans	Trumpet creeper	AIT		Sykes, Perky, and Palone 1993	SW
Carpinus caroliniana	American hornbeam	MHF	aesthetics	"	C,NE
Carya aquatica	Water hickory	MLF	timber,wildlife	"	SE
Carya cordiformis	Bitternut hickory	MMF	timber,wildlife	Sykes, Perky, and Palone 1993	C,NE,S
Carya glabra	Pignut hickory	MHF	timber,wildlife	"	SE
Carya illinoensis	Sweet pecan	MHF	timber, wildlife, aesthetics		S
Carya laciniosa	Shellbark hickory	MHF	timber,wildlife	"	N,E
Carya lieodermis	Swamp hickory	MIF	timber, wildlife	"	SE
Carya ovata	Shagbark hickory	MHF	timber,wildlife	ì	E,S,N
Carya pallida	Sand hickory	MHF	timber,wildlife	ì	S,NE
Carya tomentosa	Mockernut hickory	MHF	timber,wildlife	"	SE
Catalpa bignonioides	Catalpa	MMF	timber,aesthetics	"	E

(Sheet 2 of 10)

Table A1 (Continued)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference	Local
WOODY SPECIES (Continued)					
Celtis laevigata	Sugarberry	MMF	timber,wildlife, aesthetics	Sykes, Perky, and Palone 1993	SE,NE,C
Celtis occidentalis	Common hackberry	MMF	timber, aesthetics, wildlife		NE,SE, C
Celtis pallida	Hackberry	AIF	wildlife	Bush and Auken 1984	SE,SW,C
Celtis reticulata	Desert hackberry	AIF	wildlife	ì	SW
Cephalanthis occidentalis	Buttonbush	APC/MFS	wildlife	Sykes, Perky, and Palone 1993, Sands & Howe 1977	Nationwide
Cercis canadensis	Redbud	MHF	aesthetics		C,N
Cercidium floridum	Palo verde	AET		Pinkney 1992	W
Chamaecyparis thyoides	Atlantic white cedar	MMF	timber	Sykes, Perky, and Palone 1993	E,NE
Chilopsis linearis	Desert willow	AET		Pinkney 1992	W
Chrysothamnus nauseosus var. graveolons	Rabbit brush	AET		Dick ñPeddie & Hubbard 1977	W, SW
Clematis pitcheri	Pitcherís virginís bower	AET			C
Conium maculatum	Poison hemlock	AIT		Conard, MacDonald, Holland 1977	W
Condalia hookeri	Brasik	AET		Bush and Auken 1984	S
Cornus amomum	Silky dogwood	MHF	wildlife, water quality	, Sykes, Perky, and Palone 1993	C,SE
Cornus drummondii	Rough-leaf dogwood	MTF	aesthetics		C, N,W
Cornus florida	Flowering dogwood	MTF	timber, wildlife, aesthetics	Sykes, Perky, and Palone 1993	E,NE,S,C
Cornus stolonifera	Red-osier dogwood	MLF	wildlife,aesthetics	ì	E,SE
Corylus americana	Hazlenut	MHF	timber	ì	E,SE
Crataegus sp.	Hawthorn	MMF	timber	Boldt et al. 1978, Sykes, Perky, and Palone 1993	E,C
Diospyros virginiana	Persimmon	MLF	timber,wildlife	Sykes, Perky, and Palone 1993	SE
Elaegnus angustifolia	Russian olive	MMF			C
Euonymus atropurpureus	Wahoo	MHF			S,SW,C
Fagus grandifolia	American beech	MTF	timber,wildlife, water quality	Sykes, Perky, and Palone 1993	NE,SE,C
Fallugia paradoxa	Apache-plume	AET		Dick-Peddie & Hubard. 1977	W,SW
Forestiera acuminata	Swamp privet	MLF	aesthetics	Sykes, Perky, and Palone 1993	SE,SW
Forestiera neomexicana	New Mexican olive	AET	aesthetics		W,SW
Forquieria splendens	Ocotillo	AET		Pinkney 1992	W
Franseria dumosa	White bursage	AET		"	W

(Sheet 3 of 10)

Table A1 (Continued)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference	Local
WOODY SPECIES (Continued)					
Fraxinus velutina	Velvet ash	MLF	timber, water quality	Pinkney 1992	W
Fraxinus americana	White ash	MLF	water quality, aesthetics	Sykes, Perky, and Palone 1993	C,S,NE
Fraxinus caroliniana	Swamp ash	MFS	aesthetics	"	E,SE
Fraxinus latifolia	Orgeon ash	MMF	aesthetics	Sands & Howe 1977, Trush, Connor, and Knight 1989	NW
Fraxinus nigra	Black ash	MFS		Brinson 1993	NE
Fraxinus pennsylvanica	Green ash	MLF	aesthetics	Sykes, Perky, and Palone 1993	Nationwide
Fraxinus profunda	Pumpkin ash	MMF	timber	"	NE,SE,C
Gleditsia aquatica	Water locust	MLF	aesthetics	ì	SE,C
Gleditsia triacanthos	Honey locust	MHF	timber,wildlife, aesthetics		SE,C
Gordonia lasianthus	Loblolly bay	MMF	aesthetics	Sykes, Perky, and Palone 1993	SE,C,NE
Gymnocladus dioicus	Kentucky coffeetree	MHF	timber, aesthetics, wildlife		NE,SE,C
Hymenoclea monogyra	Burrow weed	AET		Sykes, Perky, and Palone 1993	SW
Ilex decidua	Deciduous holly	MMF/ AIF	aesthetics, wildlife	Dick-Peddie & Hubbard 1977, Sykes, Perky, and Palone 1993	Nationwide
Ilex opaca	American holly	MMF	aesthetics	Dick-Peddie & Hubbard 1977	Nationwide
Itea virginicia	Virginia willow	AIF	aesthethics		W, NW
Juglans cinera	Butternut	MHF	timber,wildlife, aesthetics	Sykes, Perky, and Palone 1993	N,NE
Juglans nigra	Black walnut	MHF	timber,wildlife	Sykes, Perky, and Palone 1993	C,E,NW
Juglans major	Nogal walnut	AET	wildlife	Dick-Peddie & Hubbard 1977	W
Juglans microcarpa	Little walnut	AET	wildlife	"	W
Juniperus virginiana	Eastern redcedar	MTF	timber,wildlife, aesthetics, water quality	Sykes, Perky, and Palone 1993	SE,E
Larix laricina	Larch	MFS		Brinson 1993	NE
Larrea tridentata	Creosote bush	AET		Pinkney 1992	W
Liquidambar styraciflua	Sweetgum	MMF	timber,wildlife	Sykes, Perky, and Palone 1993	SE
Liriodendron tulipifera	Yellow-poplar	MTF	timber,wildlife, aesthetics, water quality	"	SE,NE
Lonicera involucrata	Ink Berry	AIT		Brinson 1993	W
Lycium sp.	Boxthorn	AET		Pinkney 1992	W
Lycium torreyi	Wolfberry	AIT		Brinson 1993	W

(Sheet 4 of 10)

Table A1 (Continued)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference	Local
WOODY SPECIES (Continued)					
Maclura pomifera	Osage orange	MMF	timber,wildlife	Sykes, Perky, and Palone 1993	S,C
Magnolia grandiflora	Southern magnolia	MHF	aesthetics	Sykes, Perky, and Palone 1993	SE
Magnolia virginiana	Sweetbay	MMF	aesthetics	"	NE,SE
Menispermum canadense	Canada moonseed	AIT			C
Morus microphylla	Mulberry	AIF	aesthethics	Dick-Peddie & Hubbard 1977	SW
Morus alba	White mulberry	MMF	aesthetics, wildlife		NE,C,S
Morus rubra	Reb mulberry	MHF	timber, wildlife	"	NE,SE,C
Nyssa aquatica	Water tupelo	MFS	timber,wildlife, aesthetics	Sharitz and Lee 1985, Sykes, Perky, and Palone 1993	SE
Nyssa sylvatica v. biflora	Tupelo swamp	MFS	timber,wildlife, aesthetics	"	SE
Nyssa sylvatica	Black gum	MFS	timber,wildlife, aesthetics	"	NE,SE
Olneya tesota	Ironwood	AET		Johnson, Bennett, and Haight 1989	W
Ostrya rubra	Hophorn beam	MHF		Dick-Peddie and Hubbard 1977	SW
Oxydendrum arboreum	Sour wood	MHF	wildlife	Sykes, Perky, and Palone 1993	SE,NE
Parthenocissus inserta	Thicket creeper	MMF			C
Parthenocissus quinquefolia	Virginia Creeper	MMF		"	C
Persea borbonia	Red bay	MLF	timber,aesthetics	Sykes, Perky, and Palone 1993	SE
Philadelphus microphyllus	Mock orange			Dick- Peddie & Hubbard 1977	W
Picea glauca	White spruce	MMF	timber,wildlife,water quality	Sykes, Perky, and Palone 1993	E,NE
Picea mariana	Black spruce	MMF	timber,wildlife, aesthetics	"	NW,NE
Picea pungens	Red spruce	MMF	timber,wildlife, aesthetics	"	NE
Pinus echinata	Shortleaf pine	MMF	timber	"	SE
Pinus elliotti	Slash pine	MMF	timber	"	SE
Pinus glabra	Spruce pine	MHF	timber	"	SE
Pinus rubens	Red pine	MHF	timber	Sykes, Perky, and Palone 1993	NE
Pinus serotina	Pond pine	MMF	timber	"	SE
Pinus strobus	White pine	MMF	timber,wildlife, aesthetics	"	NE

(Sheet 5 of 10)

Table A1 (Continued)					
Scientific Name	**Common Name**	**Riparian Zone[1]**	**Value**	**Reference**	**Local**
		WOODY SPECIES (Continued)			
Pinus taede	Loblolly pine	MMF	timber,water quality	Sharitz & Lee 1985, Sykes, Perky, and Palone 1993	SE
Pinus virginiana	Virginia pine	MHF	timber	Sykes, Perky, and Palone 1993	E
Planera aquatica	Water elm	MFS	asethetics	"	E
Platanus occidentalis	American sycamore	MMF	timber,aesthetics		N,SE, C
Plantanus wrightii	Sycamore	AET		Conard, MacDonald, Holland 1977	SW, NW
Pluchea sericia	Arrow weed	MHF		Dick-Peddie & Hubbard 1977	SW
Populus acuminata	Narrow leaf cottonwood	APC	aesthetics	"	SW
Populus angustifolia	Cottonwood	APC		Brinson 1993	Nationwide
Populus balsamifera	Balsam poplar	APC		"	NW
Populus deltoides	Eastern cottonwood	MMF-AIC	timber,wildlife, aesthetics	Ware and Penfound 1949., Sykes, Perky, and Palone 1993	N,SE
Populus fremontii	Fremont cottonwood	AIF	aesthetics	Sands & Howe 1977	SW,NW
Populus grandidentata	Bigtooth aspen	MFS	timber,wildlife	Sykes, Perky, and Palone 1993	N,NE
Populus sargentii	Plains cottonwood		aesthetics	"	SW
Populus tremuloides	Quaking aspen	MMF	timber,wildlife,water quality	"	NE,NW
Prosopis juliflora	Mesquite	AET/MHF		Pinkney 1992	C,E
Prosopis pubescens	Screwbean	AET/MHF		"	C,W
Prunus americana	Wild plum	AET/MHF	wildlife	Boldt et al. 1978	C,W
Prunus serotina	Black cherry	MHF	timber,wildlife		C,NE,SE
Quercus alba	White oak	MTF	timber,wildlife,water quality	Sykes, Perky, and Palone 1993	NE,C
Quercus bicolor	Swamp white oak	MLF	timber,wildlife,water quality	"	SE
Quercus falcata var. falcata	Southern red oak	MMF	timber,wildlife, aesthetics, water quality	Sykes, Perky, and Palone 1993	SE
Quercus falcata var. pagdaefolia	Cherrybark oak	MHF	timber,wildlife, water quality	"	SE
Quercus imbricaria	Shingle oak	MHF	timber,wildlife,water quality	"	SE
Quercus laurifolia	Laurel oak	MHF	timber,wildlife, aesthetics	"	SE
Qurecus lobata	Valley oak	MHF		Conard, MacDonald, and Holland 1977	E
Quercus lyrata	Overcup oak	MLF	timber,wildlife,water quality	"	C,N
Quercus macrocarpa	Bur oak	MLF	wildlife,aesthetics, water quality		C,SE
Quercus marilandica	Blackjack oak	MHF	timber, wildlife, water quality	Sykes, Perky, and Palone 1993	E
Quercus michanxii	Swamp chestnut oak	MHF	timber, wildlife, aesthetics	"	S
					(Sheet 6 of 10)

Table A1 (Continued)					
Scientific Name	**Common Name**	**Riparian Zone[1]**	**Value**	**Reference**	**Local**
		WOODY SPECIES (Continued)			
Quercus muehlenbergii	Chinkapin oak	MHF	timber,wildlife, water quality	Sykes, Perky, and Palone 1993	S,E
Quercus nigra	Water oak	MLF	timber, wildlife, water quality	"	SE
Quercus nuttallii	Nuttall oak	MMF-MLF	timber,water quality	"	S
Quercus palustris	Pin oak	MMF	timber, wildlife, aesthetics		C,NE
Quercus phellos	Willow oak	MMF/MLF	timber, wildlife,water quality	Sykes, Perky, and Palone 1993	SE
Quercus prinus	Chestnut oak	MHF	timber,wildlife, water quality	"	C,NE
Quercus rubra	Northern red oak	MHF	timber,wildlfie,water quality	"	S,NE
Quercus shumardii	Shumard oak	MHF	timber,wildlife,water quality,aesthetics	"	C,SE
Quercus stellata	Post oak	MHF	timber,wildlife, aesthetics	"	S,SE
Quercus velutina	Black oak	MHF	timber,wildllifewater quality	Sykes, Perky, and Palone 1993	S,N,SE
Quercus virginiana	Live oak	MHF	timber, wildlfie, aesthetics	":	S,SE
Rhamnus betulaefolia	Birchleaf buckthorn	AET		Dick-Peddie and Hubbard 1977	W
Rhus diversiloba		AIF		Conard, MacDonald, and Holland 1977	W
Rhus microphylla	Little-leaf sumac	AET		"	W
Ruhs radicans	Poison ivy	MMF/AIF		Brinson 1993	Nationwide
Ribes missouriense	Missouri gooseberry	MHF			C
Robinia pseudoacacia	Black locust	MHF	timber, wildlife	Sykes, Perky, and Palone 1993	E
Rubus allegheniensis	Common blackberry	MHF/AIF	wildlife		C
Rubus hispidus	Swamp dewberry	MMF	wildlife		C
Rubus occidentalis	Black raspberry	AET	wildlife	Boldt, Uresk, and Severson 1978,	C
Salix amydaloides	Peach-leaf willow	MLF	aesthetics		SE,C
Salix caroliniana	Carolina willow	MFS	aesthetics	Sykes, Perky, and Palone 1993	SE
Salix cottettii	Bankers willow	MLF/MFS	aesthetics	"	SE
Salix exigua	Coyote willow	AET		Pinkney 1992	W
Salix gooddingii	Southwestern cottonwood	AIF/MLF	aesthetics	Sands and Howe 1977	SW
Salix hindsiana	Sand bar willow	AIF	aesthetics	Ware and Penfound 1949	C,N
Salix nigra	Black willow	MLF	aesthetics		SE,C
Salix purpurea	Purple osier willow	MFS	aesthetics	Sykes, Perky, and Palone 1993	C
Salix scouleriana	Scouler willow	AET	aesthetics	Brinson 1993	SW
					(Sheet 7 of 10)

Table A1 (Continued)					
Scientific Name	**Common Name**	**Riparian Zone[1]**	**Value**	**Reference**	**Local**
		WOODY SPECIES (Continued)			
Sambucus canadensis	American elderberry	MHF			C
Sarcobatus vermiculatus	Grease wood	AET		Dick-Peddie and Hubbard 1977	W,SW
Sassafras albidum	Sassfras	MTF	timber, wildlife, aesthetics		NE,SE
Sherpherdia argentea	Buffalo-berry	AIT		Dick-Peddie & Hubbard 1977	W,SW
Smilax bona nox	Bull briar	MMF		Bush and Auken 1984	C
Smilax hispida	Bristly/greenbriar	MMF			SW
Symphoricarpus occidentalis	Western snowberry	MMF		Boldt et al. 1978	C,NW
Symphoricarpos orbiculatus	Buckbrush	MMF			C
Tamarix pentandra	Tamarisk	APC		Pinkney 1992	W
Taxodium distichum	Baldcypress	MFS	timber,aesthetics, water quality	Sykes, Perky, and Palone 1993	SE
Taxodium ascendens	Pondcypress	MFS	timber, aesthetics, water quality	"	SE
Taxus brevifolia	Pacific yew	MMF	timber, aesthetics	Trush et al. 1989	NW,N
Thuja occidentalis	Northern white cedar	MFS		Brinson 1993	NE
Thuja plicata	Western red cedar	MHF		"	NW
Tsuga heterophylla	Western hemlock	MHF		"	NW
Tilia americana	American basswood	MLF	timber	Sykes, Perky, and Palone 1993	NE
Toxicodendron radicans	Kuntze poison ivy	MHF			C
Toxicondendron rydbergii	Redberg poison ivy	MMF			C
Ulmus alata	Winged elm	MHF	timber, aesthetics		S,SE
Ulmus americana	American elm	MMF	timber, wildlife, aesthetics		C,NE,SE
Ulmus crassifolia	American cedar	MMF	wildlife	Sykes, Perky, and Palone 1993	C,NE
Ulmus pumila	Siberian elm	MMF	timber	"	C
Ulmus rubra	Slippery elm	MMF	timber	"	C
Vitis cinera	Graybark grape	MMF			C
Vitis girdiana	Wild grape				S,W, C
Vitis mustangensis	Mustange grape	AET		Bush and Auken 1984	SW
Vitis vulupina	Winter grape	AET			C
		HERBACEOUS			
Agrostis	Bentgrass	MTF			C
Alopercurus sp.	Fox-tail	MHE/AET	wildlife	Dick-Peddie & Hubbard 1977	Nationwide
Arundo donax	Giant reed	AIT	aesthetics	"	SE,SW
Bidens sp.	Beggars-ticks	MLF			C
					(Sheet 8 of 10)

Table A1 (Continued)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference	Local
HERBACEOUS (Concluded)					
Bromus diandrus	Ripgut brome	AET	wildlife		SW,S
Bouteloua sp.	Grama	MMF, AIF	wildlife		Nationwide
Carex sp.	Sedge	MHF,AET	wildlife,aesthetics	Dick-Peddie & Hubbard 1977	Nationwide
Catabrosa aquatica	Brook grass	MTF	wildlife	"	NW, C
Chlorogalum pomeridianum	Soap plant	AET		Sands and Howe 1977	W
Commelina sp.	Dayflower	MMF			C
Cyperus sp.	Flat-sedge	MLF/AIF		Dick-Peddie & Hubbard 1977,	Nationwide
Cypres esculentus	Chufa	AIC		Ware and Penfound 1989	W
Desmodium sp.	Tickclover	AIT			C
Distichilis stricta	Salt grass	AIF		Dick-Peddie & Hubbard 1977	Nationwide
Echinoochloa sp.	Barnyard grass	MLF			C
Eleocharis sp.	Spikerush	AIF			Nationwide
Elymus sp.	Wild rye	MTF	wildlife		N, C, W
Erigeron sp.		AET		Sands & Howe 1977	Nationwide
Equisetum sp.	Horsetail	MMF/AIF		Dick-Peddie and Hubbard 1977,	Nationwide
Festuca pratensis	Meadow fescue	MMF			C
Galium sp.	Bedstraw	MHF	wildlife		Nationwide
Glyceria striata.	Fowl manna grass	MHF	wildlife		C
Helianthus grosseserratus	Sawtooth sunflower	MMF			C
Helianthus tuberosus	Jerusalem artichoke	MMF			C
Hordeum sp.	Barley	AIT		Dick-Peddie & Hubbard 1977	Nationwide
Juncus. sp.	Rush	AIT		"	Nationwide
Leersia oryzoides	Cut grass	AET		Dick-Peddie et. al 1977	W
Leptocholoa sp.	Sprangle top	MFS			C
Luzula sp.	Wood-rush	AET		Dick-Peddie & Hubbard 1977	C,W
Muhlenbergia sylvatica	Forest muhly	MLF			C
Phalaris arundinacea	Reed canary grass	MLF			Nationwide
Phyla cuneifolia	Wedge leaf frog fruit	MMF			C
Phyla lanceolata	Lance leaf frog fruit	MFS			C
Polygonum s p.	Smartweed	AIT			Nationwide
Polypogon sp.	Rabbitfoot	AET		Dick-Peddie et al. 1977	Nationwide
Potentilla sp.	Cinquefoil	MMF			C
Ranunculus sp.	Buttercup	MLF			C
Rumex crispex	Curly dock	MLF			C

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Table A1 (Concluded)

Scientific Name	Common Name	Riparian Zone[1]	Value	Reference	Local
HERBACEOUS (Concluded)					
Sanicula canadensis	Canada Sanicle	MHF			NE
Scirpus spp.	Bulrush	MHF			Nationwide
Typha latifolia	Cat-tail	MMF			W,S,SW
Viola sp.	Violet	MMF	aesthetics		C,
Xanthium gallica	Cocklebur	AIC		Sands and Howe 1977, Ware and Penfound 1989	SE,NE
					(Sheet 10 of 10)

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14. ABSTRACT

This report describes the environmental benefits of riparian vegetation and presents considerations for the incorporation of riparian vegetation into the design and maintenance of flood control projects. The report is directed toward hydraulic engineers involved in flood control channel design as well as stream restoration and habitat improvement projects.

The ability to predict or account for impacts associated with vegetation on streams and flood control projects is hampered by a lack of understanding of the physical processes that occur when water flows through and over vegetation. Vegetation can cause conveyance loss, induce sediment problems, increase flooding, and disrupt normal channel-floodplain interactions. The tools typically used for evaluating open channel flow do not typically allow for consideration of the varied effects of vegetation. Therefore, hydraulic engineers have long been reluctant to incorporate many types of vegetation into designs because of the hydraulic and sediment uncertainties.

But healthy riparian vegetation also stabilizes streambanks, provides shade that prevents excessive water temperature fluctuations, performs a vital role in nutrient cycling and water quality, improves aesthetic and recreational benefits of a site, and is immensely productive as wildlife habitat. For these reasons, the incorporation of vegetation in stream restoration and flood control projects is often desirable.

15. SUBJECT TERMS

Aquatic vegetation	Channel stability	Riparian habitat	Vegetation
Biotechnical stabilization	Flood control	Riparian vegetation	Water quality

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